THE

JOURNAL OF GEOLOGY

APRIL-MAY, 1896.

THE MAGMATIC ALTERATION OF HORNBLENDE AND BIOTITE.

IT is proposed in the following pages, which may be regarded as an elaboration of certain ideas expressed by me a few years ago, to discuss the causes of the well-known "magmatic alteration" or "resorption" of hornblende and biotite, and to suggest the possibility of certain consequences which seem to follow on this alteration[1] and which have an influence on the mineralogical composition of certain rocks.

The alteration of the two minerals in question to a granular mass of augite and magnetite is so well known to every petrographer, and such an excellent detailed description of it may be found in Zirkel's Lehrbuch (I, 716 ff.), that it is unnecessary to devote any space to a description of the facts. It must be recalled, however, that analogous alterations are extremely rare and of doubtful character in the pyroxenic minerals.

The important facts are also to be remembered that the chemical composition of both hornblende and biotite are structurally much more complex than that of the pyroxenes, and that they contain a greater variety of atoms, hydrogen and fluorine being very frequent, if not constant, constituents of both.

It must further be noted that augite is of all minerals one of the easiest to produce artificially either by dry igneous fusion or in other ways, and that melted hornblende invariably crystallizes, under laboratory conditions, as augite. Hornblende and

[1] The word *alteration* as used throughout this paper will be understood to mean only this "magmatic" alteration or "resorption."

biotite, on the contrary, have only been formed artificially in the most recent years. As far as the experiments go they seem to show that the presence of a mineralizing agent (a fluoride or silicofluoride) is necessary for the production of biotite in the dry way, while hornblende has been produced only in the wet way very recently by Chrustschoff. The negative evidence of the experiments points to the conclusion, that for the formation of either biotite or hornblende in an igneous magma pressure is a highly important if not necessary factor, while of no moment in the formation of augite.

CAUSE OF THE ALTERATION.

Current theories.—The theories in vogue to explain the alteration in question follow more or less closely Zirkel's[1] idea of a "caustic chemical action" of the magma on the hornblende and biotite crystals, and suppose either a fusion of the crystals, or their "resorption" (solution) by the surrounding magma and the subsequent crystallization of the augite out of the magma.

In regard to the magnetite there seems to be a difference of opinion, some supposing it to be not dissolved by the magma but crystallizing when the augitic constituents are withdrawn, while others seem to suppose it also to have been dissolved and recrystallized out of the magmatic solution.

These theories postulate an instability of the hornblende and biotite, or at least their instability as regards the solvent power of the magma surrounding them, under surface conditions.

While these various theories differ in details yet they may be discussed together, as the ideas involved in them are much the same and the objections to them are on the whole quite identical.

The current theories rest chiefly on the facts that the alteration proceeds from the outside inward and starts generally from crystal surfaces in contact with the magma; that the chemical composition of the magma has an apparent influence on the alteration, this being much less common in acid than in basic

[1] ZIRKEL. Mikroscop. Petrogr. U. S. G. Ex., 40th parallel, VI, 95, 1876.

rocks; that in the most glassy forms of the volcanic rocks the alteration is uncommon; and lastly that melted hornblende recrystallizes as augite.

These arguments are of great weight and will be discussed at greater length later on. Leaving them aside for the present, I would call the reader's attention to a fact often observed which they not only fail to explain but with which they seem to be quite at variance. This is the preservation of the original form of the hornblende or biotite crystal, with its sharp angles and straight edges, in a magma which has been in motion around it, as is shown by the flow structure and fragmentary hornblendes with their fracture surfaces unaltered. That the molten or dissolved zone surrounding the crystal demanded by these theories could possess sufficient cohesion or solidity to preserve its exact original form, unchanged by the, in many cases, powerful disrupting action of the moving magma, is to me quite inconceivable and passes the bounds of reasonable conjecture. Such a zone must be, in the nature of the case, more or less fluid, often as fluid as the surrounding magma, and hence easily subject to all kinds of distortion and disruption by the current. Yet such distortions as are expected are not found. In many cases the exact original form is preserved, and in the cases where the original form is lost the outlines are merely rounded by the removal of the outer portion, and the greater part, or the whole, of the remaining mass is composed of the granular alteration products.

The supposed fusion of the crystals has been accounted for[1] by the rise in temperature of the rock-mass on solidification which is demanded by theory and which has been actually observed.[2] But it has not been shown that the rise in temperature is sufficient for the fusion, nor why such an effect does not take place on the augites, which would destroy any zonal or hourglass structure. Furthermore this hypothesis cannot explain the very numerous cases of alteration which took place while the

[1] LAGORIO, Natur d. Glasbasis, Min. Pet. Mitth. VIII, 463, 1887.

[2] ROTH. Der Vesuv., Berlin, 1857, 304.

mass was in motion, and hence before solidification—an objection which is fatal.

That resorption of the hornblende or biotite substance may, and does, take place is not to be denied. The occurrence of hornblende and biotite crystals with embayments and irregular outlines, but with no alteration border, shows that here the resorbed substance has been carried off. These cases are exactly analogous to the corrosion phenomena seen in other minerals. It is indeed hard to explain why hornblende and biotite alone should be so favored as to have their substance and form left to them in the majority of cases, while quartz, feldspar, olivine and augite should lose part of their substance on corrosion so that we do not meet with a zone of different composition from their crystals or the groundmass.

The ægirine mantles about many quartzes in the basic rocks may occur to the reader as an exception. But this exception is apparent only because the two cases differ radically in kind. In the case of hornblende the change takes place within the original crystal space and is not due to a chemical combination of hornblende and groundmass substances; while in the case of quartz the change takes place outside the crystal in the groundmass and is essentially in the nature of a chemical reaction between the quartz and some of the molecules of the groundmass.

As a further objection may be mentioned the fact that, while the alteration in general starts from surfaces in contact with the magma, yet in some cases it is seen to proceed along cracks which, as far as can be seen, are untouched by it. The first objection made is, however, so difficult of explanation that it is perhaps needless to bring up more.

And after all, when we come to examine the current theories we find them rather vague and unsatisfactory. It is easy to dismiss the subject with the explanation that resorption of the hornblende and subsequent recrystallization of its substance as augite and magnetite has taken place, but it is difficult to realize how such a process takes place in actual fact with the results that we see. It is hard to see why the original substance alone should

crystallize out of the magmatic solution and take on again its original outlines, or at least the crystallographic outlines of hornblende, with changed molecular and molar structure; while the magmatic solvent, much of which is also certainly capable of crystallization under the same conditions, abandons the hornblende and solidifies as groundmass crystals or basis.

On the "magmatic" hypothesis we should expect the frequent occurrence of glass basis or groundmass among the grains, an expectation in which we are universally disappointed. It is true that we find other minerals than the two principal ones among the alteration products, but their formation is easily understood on other grounds.

Conditions of alteration.—Let us now examine briefly the conditions under which the alteration does or does not take place; which may be broadly divided into two classes—chemical and physical.

The chemical conditions relate to the magma in which the crystals are formed and in which they float, and for reasons to be seen presently we shall confine ourselves in discussing them to the volcanic rocks.

On examining the whole range of volcanic rocks the most striking fact that we notice is that the alteration of hornblende and biotite is chiefly confined to the intermediate group—those with from 55 to 65 per cent. of silica—the trachytes, andesites, phonolites and tephrites (both leucitic and nephelinic). It is of comparatively rare occurrence in the two extreme groups, the acid and the basic rocks, though more frequent in the latter than in the former.

The alteration among intermediate rocks, especially the andesites, is so extremely common that it is the exception rather than the rule to find specimens which show no, or even very few, altered crystals. Among these rocks we expect beforehand to find a greater or less amount of alteration of the hornblende and biotite (excepting in a few structural types), and are seldom if ever disappointed in our expectations. Indeed in many regions[1] the

[1] OEBBEKE, Phillipines. Neu. Jahrb., B. Bd. I, 460; SIEMIRADZKI, Ecuador, ditto, B.

altered crystals predominate largely over the unaltered ones, occasionally to the total or almost total disappearance of the latter.

When we come to the acid and basic rocks we find that, while in both the alteration is comparatively rare, yet that there is a radical difference in the cause of the rarity in the two cases. In the basic magmas there are large amounts of iron oxides, magnesia and lime which here crystallize as pyroxene and olivine rather than as hornblende and biotite, which only rarely occur. When these two do occur, however, as in the hornblende basalts, they are almost invariably altered, so that the rarity of the alteration in these rocks is due to the rarity of the alterable minerals.

The case is quite otherwise in the acid rocks, where the bivalent metals, always in small quantities, go to form hornblende and biotite, pyroxene being of rare and abnormal occurrence in the rhyolites. Yet, notwithstanding their comparative frequency, though in small amounts, the alteration of these minerals is very unusual, the biotite being only occasionally blackened on the edges, while the hornblende is seldom changed.

We find in fact that while the absolute number of altered crystals is greatest in the andesites, yet that the proportion of altered crystals of hornblende or biotite among all those present is greatest in the basalts, where it reaches nearly 100 per cent., and decreases gradually, through the various intermediate rocks to the rhyolites where it is almost zero.

The general facts show that the chemical composition of the magma is a factor in the alteration process, though the rôle it plays is a rather obscure one. That it is a causal factor, *i. e.*, that the relative basicity of the magma in the intermediate and basic rocks immediately induces the alteration, does not seem to be probable in the light of facts to be given further on. It seems to be rather modifying in its action, the alteration which would

Bd., IV, 213, 1886; BLAAS, Persia, Min. Pet. Mitth., III, 474, 1880; HATCH, Arequipa, ditto, VII, 208–360, 1886; RUDOLPH, Peru and Bolivia, ditto, IX, 294, 304, 1887; K. VOGELSANG, Eifel, Zeit. d. d. g. G., XLII, 13, 18, 1890; GROSSER, Siebengebirge, Min. Pet. Mitth,, XIII, 77, 1892; G. H. WILLIAMS, Fernando Noronha, Am. J. Sci., XXXVII, 184, 1889.

otherwise go on being prevented by the acidity of the magma in the rhyolites and allied rocks.

Turning to the physical conditions involved we find the eruptive rocks divided into two great classes; the plutonic rocks being those which in general have solidified at a great depth and consequently slowly and under great pressure, while the volcanic rocks have solidified at, or near, the surface and hence more rapidly and under little pressure. We find on examination of eruptive rocks in general that the two classes show a marked difference in the condition of their hornblende and biotite crystals.

In the plutonic rocks the hornblende and biotite (which are among the oldest components) are almost invariably unaltered, the borders being as clear as the interior and not showing any opacity or granular augite opacite aggregate. It is evident from their fresh and clear appearance that since their formation no forces have come into play (atmospheric and dynamometamorphic action being left out of account), to change them from their original condition. This invariability of non-alteration in the plutonic rocks would be absolute (so far as my knowledge goes) were it not for two exceptions. Both of these are in nepheline syenite, one from Sierra di Monchique in Portugal,[1] and the other from Serra di Tinguá in Brazil.[2] These two rocks, it is well known, are connected with peculiar dike types, and the group in general presents peculiar features. These two exceptions cannot then invalidate the general law, deduced from very numerous and world-wide observations, that in the plutonic rocks the hornblende and biotite are unaltered.

This constancy of non-alteration is in striking contrast with the behavior of the two minerals in the volcanic rocks. In these the alteration is extremely common, quite the rule, in fact, among the intermediate and basic members, though comparatively rare in the latter, owing to rarity of hornblende and biotite, and only failing completely (or practically so) at the extreme acid end.

[1] V. WERVEKE, Neu. Jahrb., 1880, II, 151.

[2] GRAEFF, ditto, 1887, II, 236, 242, 244.

In fact, the more we study the igneous rocks, the more we are impressed with the great differences that the two minerals show in the two classes, as well as with the invariability of this behavior. In the one class of rocks we find the alteration "noticeable by its absence," while in the other the tendency is the other way, and its frequency is what most strikes us.

I have emphasized these respective characters because their invariability, resting as it does on such a broad basis of observations, shows that they are facts of prime importance for the solution of the problem. When we come to look at the class of volcanic rocks more closely, we find differences in special cases which are fully as constant and, while at first sight seemingly at variance with the above observations, are seen on further study not to clash but to be an almost equally important means to our end.

While the statement that the alteration is almost constant in the volcanic rocks (except the rhyolites, etc.) is true of the great majority of structural types, yet it has often been observed[1] that in the more glassy modifications the alteration is less than in the more crystalline; so that, speaking broadly, the frequency and amount of alteration may be said to be in roughly inverse ratio to the amount of glass basis present. Hence the above remarks on the invariability of alteration do not hold good for the highly vitreous forms, the obsidians, tachylytes, etc., in which both the hornblende and biotite are as a rule unchanged. Exceptions are to be found, but they are so few that they cannot impair our confidence in the general law that alteration is roughly inversely proportional to the amount of glass basis present, or, *coeteris paribus*, to the rate of cooling.

We must conclude, then, adopting the method of concomitant variations, and the factor of composition of the magma being eliminated by the researches of Hague and Iddings[2] and others (except in the rhyolites, etc.), that the alteration of hornblende and biotite does not take place under conditions of great

[1] *Cf* ZIRKEL, Lehrb., I. 723. ROSENBUSCH, Mikr. Phys., I. 484. II. (1887) 659.

[2] Bull. 17, U. S. G. S., 1885.

pressure and slow cooling, while conditions of slight pressure and slow cooling are extremely favorable, and again very rapid cooling and little pressure are unfavorable. The last set of conditions shows that the operation requires time, the crystals remaining unchanged because solidification, or else cooling below a temperature necessary for a molecular change, took place before alteration had time to set in. Our final conclusion, then, is that a diminution of pressure, together with a high temperature continued for some time, are the conditions necessary for the alteration.

Theory proposed.—This statement of conditions is based on such a large body of observations by the best petrographers on all classes of igneous rocks and from such a great variety of localities, and the exceptions to it are so few, that it seems to me we can safely accept it in trying to frame a theory to account for the alterations. Such a statement, by showing us the conditions under which the phenomena in question occur, points the way toward their explanation. The explanation of the alteration now proposed rests at bottom on the chemical nature of hornblende and biotite.

As has been briefly noted on page 257, and as may be seen on reference to any mineralogical handbook, these two minerals are much more complex in their molecular structure than pyroxene, one of the consequences of this complexity being, as is also indicated by experiment, that great pressure is necessary for their formation in an igneous magma,[1] with probably the presence of certain mineralizing agents.[2] That the latter are present in the magma is indicated by the content of hydrogen and fluorine in them in greater or less amounts.

This idea as to the conditions of formation of the two minerals, which Siemiradzki[3] was apparently the first to propose,

[1] The cases of uralitic hornblende and secondary biotite due to meteorological or dynamical agencies are not included in this statement. Only their formation in igneous magmas is referred to, and it is well known that a mineral may be formed in several quite different ways.

[2] *Cf.* LÉVY, Structures des Roches Eruptives. Paris, 1889, 90.

[3] SIEMIRADZKI, Neu. Jahrb. Bd. IV. 307, 1886.

does not carry with it the implication that augite as well may not be formed under the same conditions (as Siemiradzki seems to suppose). On the contrary, many facts, such as the inclusion of augite in phenocrystic hornblende and the like, show conclusively that augite can be formed under the same conditions as hornblende.

It would be perhaps rash to say that under plutonic conditions the bivalent molecules tend to form hornblende and biotite rather than pyroxene, but a hint that this is the case is furnished by the general preponderance of these two minerals over pyroxene in the plutonic rocks. The predominance is not, certainly, as great as might be wished to establish this point clearly, but that it exists is quite evident on considering the much greater abundance of the hornblende and biotite bearing plutonic rocks over the augitic; the granites, hornblende and biotite syenites and diorites surpassing, both in quantity and in number of occurrences, their augitic varieties as well as the gabbros in the broader sense. This question, however, which has no especial bearing on the present hypothesis, is merely brought in parenthetically.[1]

It is evident from their freedom from alteration in the plutonic rocks that hornblende and biotite are stable under plutonic conditions down to the last moment of solidification, while their constant alteration in the majority of volcanic rocks shows that they are unstable under diminished pressure, a fact that the experiments of Becker[2] and Doelter and Hussak[3] tend to confirm.

This instability[4] under conditions of high temperature and diminished pressure is due, according to my view, directly to

[1] It may be mentioned that Brögger (Gror. Ting. Serie, Krist. 1895, 36) states that in the grorudites the hornblende evidently represents an older phase of crystallization than the ægirine.

[2] BECKER, Neu. Jahr., 1883, II, 1 ff.

[3] DOELTER and HUSSAK, ditto, I, 1884, 23.

[4] ROSENBUSCH has already recognized this idea of instability, but without assigning a reason for it (Mikr. Phys., II, 660, 1887). *Cf.* G. H. WILLIAMS, Am. J. Sci., XXVIII, 259, 260, 1884.

the highly complex chemical character of hornblende and biotite. This is in accordance with the well-known chemical law that compounds are more unstable the greater their molecular weight and the more complex their molecular structure.

The theory here presented is that we must suppose the hornblende and biotite crystals to have been formed at an early (intratelluric) period under conditions of great pressure, and probably in the presence of mineralizing agents. As they are brought near the surface in the course of the eruption the pressure diminishes while the temperature remains high, till a point is reached where the substance is no longer stable. Here a molecular change is begun, inducing at the same time a molar change, so that the chemically and physically homogeneous mass of hornblende or biotite becomes a chemically and physically heterogeneous granular mass of augite and magnetite.

The formation of a mixture of diopside or augite and magnetite out of hornblende or biotite substance is easily conceivable and chemically quite possible, in the case of biotite lime being taken from the magma. Similar changes are not at all uncommon in the range of chemical mineralogy, and the resulting masses may be properly called paramorphs.[1] Perhaps the best analogous example is that of the change of leucite to so-called pseudo-leucite, a mixture of orthoclase and nepheline, as described by J. F. Williams.[2] In the case of hornblende, on this theory, the bulk analysis of the paramorph should be identical with that of the original mineral, or almost so (as is the case with pseudo-leucite). In the case of biotite which contains no lime (or, at least, only traces), that necessary for the formation of augite or diopside must be derived from the magma, while the potash of the biotite passes into this, or goes to form accessory feldspar. Such an interchange of atoms involves no theoretical difficulties, as similar ones are extremely common in cases of pseudomorphism and metamorphism. It may also be noted that the alteration of biotite produces larger

[1] ROTH, Geologie, I. 64.

[2] Geol. Surv. Arkansas, 1890, II, 268.

magnetite grains and less augite than that of hornblende,[1] which is quite in accordance with its greater content of iron and lack of lime. No chemical difficulties are encountered in the case of the accessory alteration products, hypersthene, olivine and feldspar, the molecules necessary for their formation being present in the mother mineral.

The process requires apparently considerable time, and we may suppose that it continues from the point where instability begins till the mass becomes solid. It is possible that it may continue for some time after solidification has set in, but of this we have no evidence. Whether the magma is in motion or at rest has no effect on the alteration process, though the effects produced by a moving magma on the alteration product may have important consequences, as we shall see.

The formation of augite may take place at the same time as the hornblende, but is not hindered by diminution of pressure, and may possibly be favored by it. So that augite may and does crystallize out of the magma, either as small groundmass crystals or microlites, or as zonal accretions around phenocrysts brought up from below, at the same time that the alteration of hornblende and biotite is going on, or even after this has ceased for lack of alterable material.

The relative chemical complexity explains satisfactorily the fact that analogous alterations are seldom, if ever, seen in either the monoclinic or orthorhombic pyroxenes, or in olivine, which are much less liable to change, owing to their comparatively simple composition and structure. This also explains the recrystallization of melted hornblende as augite.

It will be evident that this theory of simple molecular change involves no change of form such as would necessarily arise on fusion or solution of the crystal. The preservation of the original shape is in accordance with the facts of pseudomorphism, and it is easily conceivable that the fine grained product should possess in many cases sufficient cohesion between its closely packed and interlocked grains to resist considerable dis-

[1] ZIRKEL, Lehrb., I, 721.

rupting force of a surrounding moving magma. In most cases, however, the mass will be somewhat incoherent, so that it will be broken up by the action of the current, yielding the rounded forms so generally observed, and leading to other consequences of importance.

It will also be seen that there is nothing in the theory incompatible with a true resorption or solution of the hornblende or biotite substance if it should be enveloped in a part of the magma in which it is soluble under the conditions prevailing. In this case, however, we would look for embayments and other true corrosion phenomena, with a disappearance of the dissolved substance, while the pseudomorphism process could go on at another, or the same, time.

It may seem, at first sight, that the starting of the alteration at the surface and its gradual progress inwards is a serious objection to this theory, in accordance with which we might think that the change should take place all at once through the whole crystal. But when we come to examine other cases of paramorphism such as the change of monoclinic to rhombic sulphur, or wrought to cast iron, we find that the changes here take place from certain definite points or surfaces (generally the latter), so that this uniform progress of alteration need not surprise us, especially in view of the fact that the alteration evidently requires time, as in all similar changes.

It is possible also that this method of progress is dependent on the hydrogen or fluorine content of the two minerals, the attraction between their molecules and those of the other constituents being lessened by diminished pressure at the temperature of the liquid magma, so that they tend to dissociate, thus causing a molecular disintegration and starting the molecular rearrangement. Such an action in their case would naturally start at the surface or along cracks, the walls of which need not be in actual contact with the magma. This action of the gaseous contents of the minerals would also explain the cases of non-alteration, in elsewhere altered crystals, where abutting against other phenocrysts.

The non-alteration in the very acid rocks is a fact which is difficult to explain by any of the hypotheses under consideration. Since the indications are that rhyolite when erupted is at a higher temperature than more basic rocks we could on the magmatic theories look for greater alteration in them than in the andesites or basalts. Since the reverse is the case their behavior militates rather against these theories. On the resorption theory proper we could also expect to find in the acid magmas a greater tendency towards solution of the ferromagnesian crystals, as is hinted at by Rosenbusch,[1] which we do not find. Glassy forms are extremely common in these rocks, and it is possible that the non-alteration is connected rather with this structural and physical peculiarity than with their chemical composition.

It is probably premature to discuss this question at present in view of the scantiness of our knowledge, so that we may merely assume that the large amount of SiO_2, and perhaps K_2O, exerts some deterrent effect on the process of alteration, of the nature of which we are ignorant. It is possible that the non-alteration in rhyolites is connected with the tendency of acid magmas to form hornblende and biotite rather than augite. It may also be suggested here that the influence of the composition of the magma on the alteration process may be analogous to the influence of the nature of a solvent on the molecular condition of the dissolved substance.[2]

CONSEQUENCES OF THE ALTERATION.

Action of the magma.—Accepting the alteration and its attendant phenomena as facts we may examine some of the consequences of this change and see what light they throw upon a few petrological questions.

The disrupting action of the moving magma current on the granular aggregate has already been referred to, yielding the rounded forms so commonly seen. This simple mechanical action of the current would tend to scatter the augite and

[1] ROSENBUSCH, Mikr. Phys., II., 660, 1887.

[2] NERNST, Theoretical Chemistry. London and New York, 1895, 387.

magnetite grains through the groundmass, and the process may often be seen, so to speak, in operation, where a tail or streamer of such grains is observed proceeding from a rounded, altered crystal.

It is not to be supposed that these grains will be resorbed or dissolved by the magma under ordinary conditions. The presence of augite microlites and crystals which have been formed down to the last stage before solidification, and the accretions about augite phenocrysts, precludes any such idea for the augite. Iddings [1] has shown that where resorptive action takes place the last minerals to crystallize should be the first to be resorbed, so that the magnetite grains are also safe from the attack of the magmatic ogre. It follows, therefore, that, provided the mass be in sufficient motion, the greater the alteration of hornblende and biotite the greater will be the abundance of augite and magnetite grains in the groundmass.

This conclusion may be supported by numerous observations:

H. Vogelsang [2] was the first to suggest that the "opacite" grains in the groundmass were derived from altered hornblende and biotite crystals by mechanical disintegration.

Zirkel [3] concludes that "many of the dark grains scattered through rocks are really the finely-distributed, powder-like particles of the pyrogenous alteration product of hornblende."

Mügge, [4] in his paper on the rocks of the Azores, makes the definite statement that augite grains as well may have been derived from altered hornblende and biotite crystals. We have also the interesting fact shown that the augites which crystallize out of the magma may be, and are in this case, of a different composition. On page 224 he says that certain groundmass olivines "appear in these cases, as sometimes in trachytes elsewhere, to have been produced from hornblende and biotite by resorption (Umschmelzung)."

[1] IDDINGS, Cryst. Ign. Rocks, Bull. Phil. Soc., Washington, XI., 105, 1892.

[2] H. VOGELSANG, Philosophie d. Geologie, Bonn, 1867, 192, *cf.* also his Die Krystalliten, Bonn, 1875, 157.

[3] ZIRKEL, Mikr. Pet. 40th Parallel, Washington, 1876, 95; also Lehrb., I., 717.

[4] MÜGGE, Neu. Jahrb., 1883, II., 1895.

Von Lasaulx[1] concludes that the rock-magma of the augite andesites of Hemmerich in the Siebengebirge must have been much more rich in hornblende at an early stage, and that the preponderance of augite, as well as magnetite, could have come about through resorption (Einschmelzung) of the hornblende. Grosser,[2] in a later work on the same region, comes to the same conclusion.

Hatch[3] notes a connection between the alteration of the hornblende and the presence of magnetite in the groundmass of certain Peruvian andesites, observing that in cases where the hornblende is "resorbed" magnetite is abundant, while in rocks where the mineral is unchanged the groundmass contains no magnetite grains. No definite mention of augite is made in this connection, but on page 359 he states that "hand in hand with the resorption of the hornblende goes an increase in pyroxene and magnetite."

Finally two examples drawn from my own experience may be given, one the hornblende basalts of Kula in Asia Minor,[4] and the other the andesites of Ægina and Methana.[5] In these the relation of the abundance of augite and magnetite grains in the groundmass to the alteration of the hornblende is well shown.

We see from these examples that in many andesites, as well as in other volcanic rocks, a part of the groundmass augites (and magnetites) have been derived from hornblende or biotite through alteration, whether "magmatic" or "molecular" it matters not.

It is possible that we have in this fact the explanation of the so frequent occurrence of imperfect grains of augite in the groundmass of many rocks. Augite and magnetite tend to be anomalous in this respect, as the groundmass crystals of the other rock-forming minerals — the feldspars, quartz, hornblende,

[1] Von Lasaulx, Sitz. ber. Niederrh. Ges. in Bonn., XLI., 155, 1884.

[2] Grosser, Min. Pet. Mitth., XIII., 77, 1892.

[3] Hatch, Min. Pet. Mitth., VII., 347, 1886.

[4] Am. J. Sci. LXVII, 121, 1894.

[5] Jour. of Geol., III, 21–46, 1895.

hypersthene, apatite and sphene — show comparatively few imperfect forms, and have a greater tendency toward definite crystallographic outlines. In augite, on the contrary, the groundmass crystals are often sharply divisible into imperfect grains and definite crystals.

Origin of some augite andesites.—By this idea of scattering of the granular alteration product of hornblende and biotite through the groundmass we are brought face to face with the question of the origin of many augite-andesites, and their classificatory separation from the hornblende and biotite-andesites. This problem has been touched upon by several writers and some discussion of it may be found in Zirkel's Lehrbuch (II, 817).

The separation of the augite from the hornblende-andesites has been opposed on the ground of the abundance of transition forms and the consequent difficulty of drawing a fast line between the two. Such an objection would however lie against almost any of the well established rock groups, and I fully concur with Rudolph[1] in his opinion of the importance of well characterized types at each end of the series.

That the two main classes may be rationally separated in general on the grounds of different mineralogical composition, together with correlated chemical and structural variation, cannot be doubted very seriously at the present time. But the alteration of hornblende and biotite tends to complicate matters somewhat

It must be stated here, and the fact must be insisted upon, that the hypersthene andesites in general, as Zirkel says, and many of the true augite-andesites are of an undoubtedly original character, *i. e.*, the component characteristic pyroxenes have crystallized normally out of the magma. On the other hand the facts of the alteration make it extremely probable that some of the augite-andesites are of a derivative character, *i. e.*, that their magmas were originally hornblendic or biotitic, but that these minerals have been replaced by augite and magnetite through the process of alteration and the consequences of the action of the moving magma on the products.

[1] RUDOLPH, Min. Pet. Mitth., IX, 316, 1887.

This idea was first broached by Von Lasaulx,[1] and his remarks are of such importance that a full quotation of the passage bearing on this point may be given:

"A conclusion which follows directly from the observations on the character of the constituents of the andesites of the Siebengebirge is this, that the less hornblende a rock holds the more it approaches a true augite-andesite, and the more the hornblende shows signs of resorption, so much the richer is the groundmass in finely divided magnetite. If . . . the hornblende is a constituent which has separated out of the fluid magma as one of the earliest at a great depth, then it would depend on how far the originally formed hornblende had undergone fusion and solution whether a rock appears in the upper regions as hornblende-rich or hornblende-poor. That augite is formed out of the magma easily and abundantly through resorption of enclosures and the earliest crystals can likewise be shown by experience; on the other hand hornblende appears to have been formed in this manner much less often. Likewise the magnetite of the groundmass can be increased by refusion of small hornblende crystals.

"An augite-andesite can therefore arise out of an original probably hornblende-andesite magma, if this remains in a state of liquidity so long that the hornblende which has been formed at a depth may be again wholly, or mostly, dissolved, and augite and magnetite be formed in its place."

The general similarity of the views expressed in the above quotation as to the origin of some augite-andesites with my own is apparent. It must be remarked, however, that the conclusions are as true of biotite as of hornblende, and also that I differ radically from Von Lasaulx in considering that the derivative augites are not crystallized out of the magma from dissolved hornblende substance, but are due to a molecular change and subsequent mechanical disintegration.

Zirkel expresses himself as against such an origin, saying that it would apply in any case not to the phenocrystic but only

[1] VON LASAULX, op. cit., 1858.

to the groundmass augites, and further that it is unscientific to connect closely a hornblende-free augite-andesite with a hornblende-andesite because part of the augite of the former could have been possibly in the condition of hornblende at an earlier magmatic period.

While not wishing to be in any degree polemical I must differ in this matter from Professor Zirkel, as it seems to me to be an inevitable conclusion from the facts that many of the groundmass augites in certain andesites have been so derived from altered hornblende substances. Mügge's example of the Azores trachytes already cited shows also that such derivative grains may attain the size of phenocrysts and hence be reckoned as such, through accretion of crystallizing augitic substances. Such a derivative origin must not, however, be attributed to all phenocrysts nor to the well formed augite-microlites and groundmass crystals. Nor is such an attribution necessary, as I have already pointed out that hand in hand with the alteration of hornblende may go on the crystallization of augite out of the magma. It may be mentioned here that Zirkel[1] speaking of the hornblendes in pyroxene-andesites says that they give the impression that they had nothing to do with those conditions of solidification in which the rock-mass as it exists at present was produced, from which the inference is to be drawn that they have been formed at a much earlier period.

But when Zirkel brings the charge of being unscientific against the idea of the derivation of augite-andesites from hornblendic magmas, he touches upon what seems to me to be a vital and important point in the question. If it were sweepingly asserted that all, or even the most, of the augite-andesites were to be connected with hornblendic magmas[2] his reproach would be justified, as being an unwarranted and too broad a generalization from the facts. But if it can be shown that certain augite-andesites are of independent origin while others are derivative from a previously hornblendic magma, then we have advanced a step

[1] ZIRKEL, Lehrb. II, 811.

[2] As VON LASAULX perhaps seems to do.

in our knowledge of this group of rocks—a step which may lead to the extension of our knowledge in other directions. The question as to whether the knowledge of such an origin should affect the present, classification is a question apart and need not be discussed here.

Acid augite-andesites.—A consideration of the phenomena already discussed, as well as others to be mentioned presently, has led me to the conclusion that, besides the normal augite-andesites which make up the greater part, such derivative augite-andesites do exist, in which a large part of the augite present is due to the alteration of hornblende. What the grounds are for this view I shall endeavor to show, though my remarks must be taken as suggestive of what may be the case, rather than as even approaching a full discussion of the subject.

It is quite well established that hornblende and biotite are the prevalent, or one might say favorite, ferro-magnesian silicates of the more acid rocks, though ægirine is abundant in acid phonolites and some trachytes, while augite is characteristic of the more basic rocks. This being so we could expect *a priori* to find the augite-andesites more basic than the hornblende or biotite-andesites. While this is the fact in many cases, yet exceptions are numerous, the abnormal acidity of many of the augite-andesites being remarked upon by Zirkel[1] and Rosenbusch,[2] as well as by others.

Some particular instances of the high acidity of augite-andesites occurring together with other andesites may be given. On the volcanic line in the Ægean Sea are found the two centers of Santorini, which has poured forth almost exclusively pyroxene-andesites, and Ægina-Methana, where hornblendic andesites and dacites are abundant as well as pyroxene andesites. I have elsewhere[3] pointed out the similarity in the general magmas of the two centers, and yet when we come to examine the rocks of the two districts in reference to the present point we meet with a

[1] ZIRKEL, Lehrb. II, 802.

[2] ROSENBUSCH, Mik. Phys. II, 651–683, 1887.

[3] JOUR. OF GEOL. III. 166, 1895.

somewhat striking result. In Ægina-Methana the analyses of the hornblende-andesite (excluding segregations) show an average silica percentage of 59.41, while at Santorini the pyroxene andesites are very acid, the silica average of the analyses quoted in the paper just cited, being 61.41 per cent., and the latest products of eruption range from 66.15 to 68.89.

Again we find in the Washoe District,[1] the Yellowstone Park,[2] Colombia,[3] and Ecuador[4] that eruption of the hornblende and pyroxene-andesites have taken place, and that many of the latter are as acid as, or more so than many, of the accompanying hornblende-andesites. Other instances of the abnormal acidity of augite-andesites that might be quoted are not rare, and the fregency of such occurrences is certainly surprising in view of what we might *à priori* expect.

In 1881 Gümbel[5] pointed out that the andesites of the Andes could be referred to two types, which he called the trachytic and the basaltic, the former with over, and the latter with under, 57 per cent. of silica. Later, in 1883, Cross[6] suggested that the augite-andesites may be divided into three groups; the "trachytic" with a high percentage of silica, the "basaltic" which are the most basic and pass into the true basalts, and the "intermediate" normal augite-andesites with a silica percentage of 56 to 60.

That the "intermediate" and "basaltic" augite-andesites have had the greater part at least of their augite crystallized out of the magma in a normal way, and hence that they are really augite-andesites in a true sense of the word, seems to be generally the fact; though cases might be brought up in which a derivative origin could be rightly attributed to a part of the augite even of these.

[1] HAGUE and IDDINGS, Bull U. S. G. S. No. 17, p. 33. *cf.* also CROSS, Laccolite Mt. Groups, XIV, Rep. U. S. G. S. 227, 1895.

[2] IDDINGS, Electr. Peak, XII Rep. U. S. G. S., 627, 628, 1892.

[3] Küch, Petr. vulk. Gest. Rep. Colombia, Berlin, 1892, 78, 79.

[4] Siemiradzki, op. cit., 205, 206.

[5] GÜMBEL, Sitz. ber., Münch. Akad., XI, 365 ff., 1881.

[6] Cross, Bull. No. 1, U. S. G. S., 36, 37, 1883.

Leaving these aside, we may confine our attention to the acid, "trachytic," augite-andesites. In the magma of such a rock we could naturally expect the formation of hornblende or biotite rather than augite.

Zirkel[1] explains the high acidity by the abundant presence of a glass basis which is often much more acid than the rock itself, as shown by Lagorio's[2] analyses. This explanation, however, only shifts the difficulty one step back, or rather states it in another form, since Lagorio's analyses also show that in basalts[3] the basis contains almost exactly as much silica as the rock.

The explanation which is suggested here is that these acid augite-andesites are derived from original hornblende or biotite-andesitic magmas. The magma came up with crystals of hornblende or biotite already formed, and these underwent alteration and disintegration as already described, while at the same time the rest of the ferro-magnesian molecules present in the magma crystallized as augite or hypersthene under the existing low pressure conditions.

Against this view may be brought a number of objections, one of those which most naturally occurs being that in the very acid rocks, as the rhyolites, the tendency is for the hornblende and biotite to remain unaltered. This objection is of weight, but it must be remembered that the acid andesites in question seldom, if ever, attain to the high acidity of the rhyolites, and further, that they are chemically quite different otherwise.

A detailed study of the various augitic andesites, and especially the more acid ones, would undoubtedly throw much light on the question and show which explanation (if either) was correct. Such a study would, however, carry us beyond the bounds of this article, and is, moreover, impracticable for me at present.

Variation with geological occurrence.—It is evident, from the facts of the alteration, that the physical conditions under which

[1] ZIRKEL, Lehrb. II, 819.

[2] LAGORIO, Min. Pet. Mitth., VIII, 458, 467, 1887.

[3] LAGORIO, op. cit., 479.

the magma is erupted and consolidated would, to a certain extent, control the formation of augite on this hypothesis. We may therefore examine a few cases of variation of mineralogical composition with geological occurrence which seem to bear out the view that many acid augite-andesites (and some of the more basic ones) are derived from hornblende-andesitic magmas of normal composition.

In the andesites of the Auvergne, as recently described by Fouqué,[1] the hornblende and biotite crystals are generally altered in the effusive lava streams, while in the very glassy effusives and in the dike rocks (which, according to Fouqué, have cooled quickly) they are fresh and augite is rare. It may be noted here, *en passant*, that in these rocks the presence of dusty inclusions in the apatite crystals seems to go hand in hand with the hornblende.[2]

In the augite-andesite flows of Mount Cimino, Deecke[3] observed that biotite predominates on the borders, while augite takes its place in the interior, of the streams.

The difference observed by Hazard[4] in the stock and sheet basalts of the Lausitz is noteworthy. The latter are normal olivine basalts, with or without nepheline, while the former are hornblende basalts. His conclusions are that hornblende separated out as phenocrysts only in the eruptive canal, that it was gradually resorbed, changing into augitic substance, and that further on, when the rock spread out as a sheet, or was injected into cracks, olivine invariably separated out. "It is hence possible to judge of the nature of the occurrence of our basalts (whether sheet or stock) from the constituents."

The explanation of such occurrences on the theory here suggested is quite simple. Hornblende and biotite, which have been formed at a depth, are preserved intact when the

[1] FOUQUÉ, L'Etude des Feldspaths, Paris, 1894, 193–270.

[2] *Cf.* BLAAS, Jung. Erupt. Gest. Persiens. Min. Pet. Mitth., III., 476 ff., 1880. Also, MERRILL, Erupt. Rocks fr. Montana. Proc. U. S. Nat. Mus., XVII., 642, 1895.

[3] DEECKE, Neu. Jahrb. B. Bd., VI., 231, 1889.

[4] HAZARD, Min. Pet. Mitth., XIV., 303 ff., 1894.

magma solidifies under sufficient pressure, as in the Lausitz stock; or where it cools so quickly that time is not given for alteration, as in the Auvergne dikes or the borders of the Mount Cimino streams. They undergo more or less alteration (and are hence replaced by augite) when such time is given them while they are simmering under slight pressure in the throat of the volcano, as seen in the lava flows of Auvergne and the Lausitz. In the case of the Mount Cimino flows we may suppose that the slow cooling of the interior under slight pressure gave opportunity for the replacement of the biotite by augite.

There are certain other cases where it seems possible that for some reason the magma was brought near the surface before the formation of hornblende or biotite had taken place to any extent, so that the crystallization of augite out of the magma took place, instead of either of the two other minerals.

As an illustration of this may be mentioned the volcanoes of Santorini. Here the highly acid pyroxene-andesites ejected by the later eruptions which formed the small island cones in the center of the bay show in the abundant glassy groundmass a large preponderance among the augites of well-formed prismatic microlites, as well as abundant hypersthene prisms, neither of which could be due to the alteration of hornblende, while augite grains are quite rare. The lava flows which go to make up the external crater ring of Thera and Therasia are in general much more crystalline and at the same time contain many more imperfect grains of augite, as I gather from examination of specimens collected by myself, and from some of Fouqué's remarks.[1] In this connection it is of interest to note that the hornblende crystals in the hornblende-andesites of Acrotiri very seldom show alteration phenomena.[2]

These explanations may seem forced or unnecessary to many, but they are only offered as suggestions of the applications of the idea of the instability of hornblende and biotite under eruptive conditions to certain problems of petrology. The forces

[1] FOUQUÉ, Santorin, Paris, 1879, 291, *et al.*

[2] FOUQUÉ, Santorin, 357.

involved in an eruption and the conditions under which the magma reaches the surface are probably so complex and certainly to so large an extent unknown to us that any explanation of such phenomena must be, after all, largely mere speculation at the present time.

Still it must be granted that the explanation of the above facts based on the process and consequences of alteration are within the bounds of reason, and our brief review points rather to than away from the conclusion that alteration of hornblende or biotite is responsible for a great part of the acid augite-andesites, as well as some of the more basic members of the group.

The foregoing remarks lead us directly to the consideration of another application of the ideas advanced in these pages to theoretical petrology, which may be briefly touched upon before closing this paper. I refer to the succession of erupted rocks at volcanic centers. In many places we find pyroxene-andesites among the later rocks following hornblende or biotite-andesites. Thus in the Eureka district the order of succession as given by Hague[1] is: hornblende-andesite, hornblende-biotite-andesite, dacite, rhyolite, pyroxene-andesite, and lastly basalt. Again at Sepulchre Mountain[2] the lower breccias are hornblende or biotite-andesites, while the upper and consequently later breccias are almost wholly of pyroxene-andesite. While recognizing the fact that the causes and circumstances involved are extremely various and complex, it may be suggested that such successions may be due in part to causes similar to those already spoken of in connection with the variation of mineralogical composition with geological occurrence; namely, that the hornblende or biotite of the original magma may have been replaced by augite during a period of liquidity under diminished pressure.

SUMMARY.

After a brief discussion of the current theories referring the alteration of hornblende and biotite to a resorptive action of the

[1] HAGUE, Geol. Eureka Distr., Mon. XX, U. S. G. S., 290, 1892.

[2] IDDINGS, op. cit., 634, 635.

magma and a statement of certain objections to them, the conditions under which the alteration does or does not take place are described and the conclusion arrived at "that a diminution of pressure together with a high temperature continued for some time are the conditions necessary for the alteration."

The theory is then proposed that the two minerals are stable in a molten magma only under plutonic conditions, and that the alteration is simply a molecular rearrangement induced by the diminished pressure in volcanic conditions.

The instability of hornblende and biotite as compared with pyroxene is due to their much more complex chemical constitution.

The influence of the chemical composition of the magma is described, but a discussion of it is held to be premature at present.

The disrupting action of the surrounding moving magma in the granular alteration product is touched upon, and it is pointed out that many of the groundmass augites and magnetites must have been derived from altered hornblende or biotite crystals.

It is also suggested that some of the augite-andesites, especially the more acid ones, may owe their augitic character to the alteration and subsequent disintegration of previously existing hornblendes or biotites, in accordance with the views of Von Lasaulx.

Finally, several applications of this idea to the explanation of certain rock occurrences and the succession of volcanic rocks are given. HENRY S. WASHINGTON.

ON THE ORIGIN OF THE CHOUTEAU FAUNA.

In a recent number of the JOURNAL OF GEOLOGY appeared an interesting paper discussing the Chouteau fauna of southern Missouri and its relations to the geographical conditions of the region in which it lived and to the other faunas living before it appeared.[1]

Although personally acquainted with the careful work done by the author on this and associated faunas, having gone over much of the ground discussed in this paper with him, still I am not quite prepared to accept the author's interpretation of his facts. And it is because his conclusions seem in some degree to be based upon principles which I have defended in papers already published, that I feel called upon to state in particular my reasons for dissenting from two of the opinions there expressed. The first of these opinions is expressed in Mr. Weller's proposition that the Chouteau fauna of Missouri, although not identical with it, was contemporaneous with the Chemung fauna of New York (p. 916). The second opinion is the conclusion, drawn from a comparative study of the genera and species of the fauna, that it arose from the mingling of two faunas, the one coming from the east, and represented in Devonian time by the Hamilton fauna of New York, and the other, the general Devonian fauna of Europe represented by the middle Devonian fauna of Iowa and British America.

The first of these conclusions seems to be consistent with, and but an extension of views advanced by me regarding the shifting of fauna.[2] But in order to speak of a fauna as moving from place to place and as occurring in one place above or below

[1] A Circum-insular Palæozic Fauna, by STUART WELLER, JOUR. GEOL., Vol. III., pp., 903-917.

[2] Proc. Amer. Assoc. Adv. Sci., Vol. XXXIV., pp. 222-234, 1886, and Amer. Geol., Vol. X., pp. 148-169, 1892.

the horizon it occupies in another, it is necessary to prove the identity of the moving fauna in its different localities; and, second, to have a continuous datum-horizon, either above or below, with which to measure its lower or higher position. Neither of these conditions are present in the case of the Chouteau fauna.

Furthermore, if the Chouteau fauna of Missouri were equivalent to the Chemung, its species must have descended from ancestors living before the Chemung period; but if it followed the Chemung, it must have been descended from a fauna living in Chemung time. The presence in the Chouteau of such species as *Productus hallana* (=*dissimilis*) and *Rhynchonella* (*Pugnax*) *acuminata* does not signify identity of age with the base of the New York Chemung, for two reasons. First, they belong to a part of the fauna which was directly continued up into the Carboniferous. It was this peculiarity which led to designating the fauna containing them as having a "Carboniferous aspect." The Hamilton fauna of New York lacked this Carboniferous aspect, while the middle Devonian faunas of Iowa and of Europe possess it, and it was this fact which suggested the interpretation of the Cuboides zone as evidence of the incursion of the new fauna from the west into the New York area.[1]

The second reason is that the presence of these species in the Chouteau does not indicate that the fauna is Devonian in the face of its many species of distinctly Carboniferous age, any more than their presence in the High Point fauna pointed to its Carboniferous age because *Rhynchonella acuminata* was a typical Carboniferous form. The fact that they are both contained in the typical Devonian beds of Iowa explains their presence both in the New York and Missouri rocks, but does not indicate identical age. The statement about "appearing as they do for the first time after the removal of the land barrier" furnishing good ground for this correlation, ceases to be forcible when we put the question, how do we know anything about the time the barrier was removed, except through the testimony of

[1] Bull. Geol. Soc. Amer., Vol. I., pp. 481–500, 1890; Amer. Jour. Sci. (3), Vol. XXV., pp., 97–104, 1883.

the fossils? Since the faunas are not the same it is necessary to assume some kind of barrier to separate them if they were contemporaneous.

But there seem to be very good reasons for continuing to believe that the two faunas are not contemporaneous, three of which are as follows:

1. The general facies of the fauna (generic as well as specific) is that of the typical Carboniferous faunas of both America and Europe, while the Chemung fauna is typically Devonian.

2. Several of the genera and species of the Chouteau fauna are not known in any Devonian rocks of America or Europe, but are present in other Carboniferous rocks of both America and Europe.

3. The other faunas which present closest relationship to that of the Chouteau are the Kinderhook, Marshall and Waverly, and wherever these faunas are known to succeed fossil-bearing rocks in continuous sections, they are above the Chemung faunas.

Until some evidence is at hand to show that one or other of these propositions does not represent the facts, it would seem to be necessary to regard the Chouteau as of more recent age than the Chemung of New York.

The second point, the dual origin of the Chouteau, seems to be a legitimate extension of the general principle assumed by me in explaining the cuboides[1] and succeeding faunas in New York state. It was with the expectation of finding this to be the fact that I gave the paper the same searching scrutiny which I found it necessary to give my own notes on the Cuboides fauna before I published them. As Mr. Weller states that he believes "the key to the whole problem (of the origin and evolution of the Mississippian fauna) is to be found in the dual origin of the faunas" as set forth in his paper (p. 915), the importance of making sure that there was a dual origin is apparent.

If, however, we have no evidence of any further duality of origin than that supposed to account for the Cuboides fauna in

[1] The Cuboides Zone and its Fauna, Bull. Geol. Soc. Amer., Vol. I., pp. 481–500.

the New York Chemung, it will promote the main investigation, in which I am as thoroughly interested as Mr. Weller can be, to have the fact clearly expressed at the outset.

The belief in the dual origin of the Chouteau fauna is drawn by Mr. Weller from an analysis of the fauna itself. I have examined the lists and the argument for new evidence bearing upon the general problem of the movement and modification of the fossil faunas concerned, but the evidence appears to me conclusive in proving a single and direct origin from the one general European type of Devonian represented already in the Devonian faunas of Iowa and other regions of the north and west.

Critical examination of the genera listed as belonging to the "East-American Devonian Province," but wanting in the "West-American and European Devonian Province" does not confirm the opinion of an origin for any of the genera directly from the former eastern province.

The genera so listed are *Aviculopecten*, *Cardiopsis*, *Edmondia*, *Pterinea*, *Sphenotus*, *Straparollus*, *Gennæocrinus*, *Platycrinus*, *Scaphiocrinus*, *Michelinia*.

Regarding them the following comments may be made:

Aviculopecten is reported in numerous species as European Devonian by Frech[1] and Tscherneyschew.[2]

Cardiopsis is a form of such uncertain generic affinities that the absence of the genus should not be concluded from the absence of the name in lists of foreign faunas. The close relationship of the one species, recognized by this generic name from America by Hall, to *Cardiomorpha*, *Megambonia*, *Dexiobia* and *Dualina* is sufficient to prevent it from furnishing any positive evidence of origin outside of the typical European Devonian.

[1] FRECH, Die Devonischen Aviculiden Deutschland, K. Preuss, Geol. Lands, Abhandl.

[2] TSCHERNEYSCHEW, Special Karte v Preuss, a Thüring, Staaten, Bd. IX. bft. 3, 1891.

Die Fauna des unteren Devon am Ostabhunge des Ural. Mem. du Comité Geol., Vol. IV., No. 3, 1893.

Edmondia De Koninck is a form of doubtful affinities and was described from Carboniferous specimens. Although it occurs in New York it is there a Chemung form, and on the theory that the Chouteau is later than the Chemung, there is no difficulty in supposing a common origin for its species. For if we apply the theory that these species came from the eastern Hamilton, we have the same reason for so accounting for the origin of the *Edmondias* of European Carboniferous, which is evidently absurd.

Pterinea Goldf. is a genus of wide range, from the Silurian to the Carboniferous, and its absence from a particular list of species in Devonian time cannot be taken as evidence that it was not then living under appropriate conditions in the same seas.

Sphenotus, until distinguished by Hall, in 1895, was recorded under the name *Sanguinolites* McCoy, or *Cypricardia* Lam., or *Cypricardinia* Hall. The genus under these names was known in the European Devonian, and one does not need to look to the eastern New York Devonian for its origin in the Chouteau.

Straparollus Montf. is reported under that name in Europe from the Silurian to the Triassic, and it is an ancient type and should not as a genus be used as indication of local origin of any fauna so late as the Carboniferous era.

All the other genera of Lamellibranchiata and Gastropoda, as well as all the Brachiopoda named in the list were known in the western or European Devonian fauna.

The crinoids mentioned, if not included in lists of European Devonian species may be there omitted because they did not appear until the Carboniferous time, in which case we have to account for their presence there as well as in America, or, as in the case of *Platycrinus* and *Scaphiocrinus*, they are only rarely found below the Carboniferous, and have to be accounted for as newly evolved genera rather than as descendants of species of the same genus in lower rocks.

The case of *Michelinia* must have been an oversight, for the genus is reported under that name from the Devonian of Europe,

and under the name *Pleurodictyum problematicum* Goldf. is a characteristic Devonian form of Europe as well as America.

Since all other genera in the list are known to have been present in the western Devonian fauna, there appears no positive evidence of a generic character to point to any double origin of the fauna.

Mr. Weller also cites a number of species as evidence of origin from two sources. Those traced to species in the western Devonian fauna require no comment; those for which an eastern origin is suggested are the following: *Athyris hannibalensis* Swallow, (*A. spiriferoides*); *Leptæna rhomboidalis*; *Orthis Michelini* (*O. vanuxemi*): *Eccyliomphalus paradoxus* (*E. laxus*); *Loxonema cf. hamiltonæ*.

Regarding the origin of these species, it may be said in general that the presence of closely allied forms in one Devonian fauna and nothing at all like them in a second great province, might be regarded as pointing to an origin from the first rather than the second source, but if there are species with equally close affinity in both provinces, then some other evidence must appear before we can say from which the later fauna has arisen.

Athyris hannibalensis may have found its ancestors among the common and very variable *A. concentrica* von Buch, of the European Devonian, as well as from the more specialized *A. spiriferoides* of the New York Hamilton.

Leptæna rhomboidalis is such a widespread, old and variable form that it would not be safe to say that it was wanting in any complete Devonian fauna.

Orthis michelini may have arisen from the *O. vanuxemi* of the Iowa Hamilton as well as from the same species in the eastern fauna.

Any species of genera of such wide range and variable character as either *Eccyliomphalus* or *Loxonema* cannot be safely cited as evidence without particular study and the discovery of some special distinguishing mark.

Eccyliomphalus Portlock is cited as a synonym under *Phanerotinus* Sow. by Zittel as having a range from Silurian to the Car

boniferous[1] and Hall[2] includes that genus as a synonym under *Euomphalus*, which is abundantly represented in the European Devonian fauna.

The genus *Loxonema* is as old as the Ordovician and the species are all so much alike in their general habit and variations that in order to trace the origin of any particular Carboniferous species, it would be necessary to show that it possessed some distinctive mark found in the species of some particular Devonian province and absent from the representatives of the genus of all other Devonian faunas. Thus we are led, by a critical review of both the genera and species, of which an origin from outside the Mississippi province of Devonian time is suspected, to the conviction that there is no positive evidence of such a course. On the other hand there seems to be no reason to doubt the natural succession of the Chouteau fauna from the Devonian fauna already in the province.

Although there seems to be little or no evidence that the Chouteau fauna was not all derived from one common source, it is not impossible that there may be traces of species which were not descended from any Devonian species of Europe. If the evidence brought forward in the paper on the Cuboides zone will bear the interpretation put upon it, there was such a mingling of two quite distinct faunas at the opening of the Chemung period in the New York area. There are no facts known to me to prevent the supposition that the Chouteau fauna may have species derived from the older fauna, but Mr. Weller does not mention any such facts, and I am not aware that there are any.

If it could be shown that the Chouteau fauna was of the same age as the base of the Chemung, it might be inferred that the mingling of faunas from different sources, which is supposed to have taken place in the New York region, affected also the faunas in the Ozark region of Missouri; but if the Chouteau is later than the Chemung, as I believe was the case, then the

[1] Handbuch der Palæontologie, II., p. 207.

[2] Palæontology, New York, Vol. V., Part II., Text, p. 54.

mixed fauna already occupied the eastern area when the Chouteau began, and from the evidence of the distribution of the Marshall and Waverly faunas, it is probable that it occupied the whole of the marine waters then lying over the interior of North America.

In conclusion I wish to emphasize a particularly valuable point made in the paper, viz., the connection between a new fauna and the sinking of the land. The theory of my Cuboides zone paper required some such hypothesis as this to account for the sudden incursion of the general western and northwestern Devonian fauna over the New York area. Mr. Weller has suggested a reasonable solution of the problem. But there is a still further inference to be drawn from this and similar facts. May not the occupation by the ocean of recently depressed land and the changed conditions of environment thus brought about, be a fertile and general cause in the modification of the faunas? From the facts already known, the inference seems quite probable that the initiation of new faunas, containing new genera, as well as new species, which is observed on tracing the succession of formations upwards in time, is intimately associated with the occupation by the seas and their contained organisms of recently depressed land surfaces.[1] Such radical modification of the conditions of environments as would thus take place furnishes a reasonable condition for the special activity in evolutional processes, which is indicated by the sharply distinct character of the faunas immediately following an unconformity such as is often noticed. The selective effects of migration from the midst of a general and adjusted fauna into new conditions of environment will undoubtedly account for some of the faunal changes which were taking place throughout geological time; but nowhere in a series of continuously forming strata is found such definiteness of grouping of the species of a fauna as after an unconformity, indicating depression of the land after a period of elevation and erosion.

HENRY SHALER WILLIAMS.

NEW HAVEN, CONN., March 2, 1896.

[1] See Ortmann's discussion of isolation as a factor in evolution. *Grundzüge der marinen Tiergeographie*, June 1896.

NORTH AMERICAN GRAPTOLITES.[1]

II. VERTICAL RANGE.

WITHOUT attempting to discuss at length the general aspects of this subject, attention may be directed to the following points:

1. The vertical range of the American species presents a complete parallel to the range in other countries. This parallel is not a general one only, but is exceedingly detailed, extending beyond the genera down to the species, which in each horizon correspond to those of the equivalent European horizon almost without exception, although of course not every European species occurs in America, or vice versa. Still the number of species common to the two sides of the Atlantic is surprising, and it will doubtless be increased by future research.

2. This detailed correspondence furnishes good ground for the expectation that eventually the American strata, like the European, will be mapped out, zone above zone, and for the hope that here, too, the graptolites may ultimately become one of the mainstays of stratigraphy. Much has of course yet to be done, but the peculiar associations of species in several collections so nearly parallel those which abroad characterize particular zones, that it is difficult to believe that here they have a different significance.

3. The extent of the range of the group as a whole, is unprecedented, as it extends from the Cambrian to and into the Carboniferous.

4. A striking peculiarity of the American fauna is the almost entire absence of the great European family of the *Monograptidæ*

[1] Continued from THE JOURNAL OF GEOLOGY, Vol. IV., No. 1, January-February, 1896, p. 102.

with its three genera and more than 100 good species. In America only one genus and two species are known, one of them from Arctic America. One reason for this absence is undoubtedly the predominance of limestone and the scarcity of shale in most of our Upper Silurian formations, but it cannot but be suspected that future collections may yield some of that wealth of forms to which European graptolithologists have long had access.

CAMBRIAN.

Genus and Species	Lower	Middle	Upper						
	Georgia Shales (Vermont)[1]	Acadia Group (St. John, N. B.)[2]	St. John (N. B.) Group (Div. 3.)[2]			Canada[4]			Upper Mississippi Valley[5]
			b	c	c'	Oldhamia zone (purple Farnham shales)[6]	Dictyonema-Olenidae zone	Dictyonema flabelliforme zone (Cape Rosier)	
Phyllograptus	?								
? cambrensis	W								
Bryograptus			—	—				—	
lentus				M[3]					
multiramosus								G	
patens			M	M[3]					
? retroflexus?			M[3]						
spinosus			M	M[3]					
sp.								L	
Clonograptus								L	
Dichograpsus				—					
proximatus				M[3]					
Staurograpsus								L	
Climacograptus	?								
? emmonsi	W								
Protograptus		—							
alatus		M							
Dendrograptus		?			t				—
hallianus									P
? primordialis		M							
Callograptus				—					
sp.				M[3]					
Dictyonema			—	—	—		—	—	
flabelliforme			M[3]	M[3]			L	L	
acadicum			M	M	M				
confertum (Lnrs *MS.*)?.			M	M					
norvegicum?				M	M				
Oldhamia (like O. radiata)						L			
Olenidae							L		

NOTES TO CAMBRIAN TABLE.

G signifies *fide* R. R. Gurley.

L signifies *fide* Charles Lapworth.[4]

M signifies *fide* G. F. Matthew.[2]

P signifies *fide* H. A. Prout.[5]

W signifies *fide* C. D. Walcott.[1]

[1] Walcott, Bull. 30, U. S. Geol. Surv., 1886, pp. 92–94.

[2] Matthew, List of Fossils found in the Cambrian rocks in or near Saint John, N. B., 1892, p. vi.

[3] Matthew, Trans. N. Y. Acad. Sci., 1895, pp. 262–273, Pls. XLVIII.–XLIX.

[4] Lapworth, Trans. Roy. Soc. Can. for 1886, V, sect. IV., p. 168.

[5] Prout, Amer. Journ. Sci., 1851, XI., p. 187.

[6] The shales are of Sillery age (*fide* Ells; see Walcott, Proc. U. S. Nat. Mus., 1894, XVII., p. 313) and should probably be placed at a higher level in (perhaps at the summit of) this table (*cf.* Walcott, Amer. Jour. Sci., 1890, XXXIX., pp. 112–114.)

ORDOVICIAN.

Genus and Species.	Lower.												Middle [12]					Upper [12]						
	Calciferous. [1]							Chazy [11]					Trenton Limestone	Lower *Dicellograpsus* Zone.		Upper *Dicellograpsus* Zone.		Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones								New York and Canada	Arkansas [13]	Cove Fields, etc. [14]	Magog, Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
	St. John Group (summit) [2]	Gros Maule [3]	Main Pt. Levis Zone [1]	Miscellaneous [4]	Phyllograptus anna Zone [5]	Pt. Levis [1]	Arkansas	Nevada [1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.											
Phyllograptus			—		—		—	—															
angustifolius																							
anna	....	....	....	....	H L	....	G	G															
ilicifolius																							
" mancus (Lapworth var. *MS.* [6])	....	....	L G																				
loringi																							
typus	....	....	....	....	....	....	? G																
sp. indet	....	....	....	....	....	....	....	G															
Schizograptus			—				?																
amii (Lapworth *MS.* [6])	....	....	L G																				
rarus (Lapworth *MS.* [6])	....	....	L G																				
? sp.	....	....	....	....	....	....	G																
Goniograptus M'Coy																							
thureaui selwyni	....	....	....	A																			
Dichograpsus	—	—	—			—	—																
abnormis	....	....	....	....	....	G																	
flexilis	M	....	G																				
logani	M	....	....	....	....	G																	
milesi [7]																							
octobrachiatus	....	....	G																				
octonarius	....	H																					
ramulus	....	....	G																				
remotus	....	....	G																				
rigidus	....	....	G																				
sp.	....	....	....	....	....	....	G																
Tetragrapsus	—	—	—		—	—	—																
acanthonotus	....	....	G																				
alatus																							
approximatus	....	....	G																				
bigsbyi	....	....	G																				
crucifer																							

ORDOVICIAN—*Continued.*

Genus and Species	Lower												Middle[12]				Upper[12]					
	Calciferous[1]								Chazy[11]				Trenton Limestone	Lower *Dicellograptus* Zone		Upper *Dicellograptus* Zone	Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones																
	St. John Group (summit)[2]	Gros Maule[3]	Main Pt. Levis Zone[1]	Miscellaneous[4]	Phyllograptus anna Zone[5]	Pt. Levis[1]	Arkansas	Nevada[1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.		New York and Canada	Arkansas[13]	Cove Fields, etc.[14]	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Tetragrapsus—*cont'd.*																						
denticulatus	....	....	G																			
fruticosus	....	....	G	....	H	L																
headi																						
hicksi	....	....	....	A																		
quadribrachiatus	M	....	G																			
serra	....	H	G	....	H	G	G															
sp.?	M																					
Holograptus			?		?																	
? richardsoni	....	....	G	....	H																	
Didymograpsus	—	—	—		—	—	—	—	—	—	—	—		—	—							
arcuatus																	?[30]					
bifidus	....	....	....	....	H	G	....	....	G[11]													
bipunctatus																						
caduceus	....	....	....	....	....	....	? G															
convexus	....	....	....	....	....	....	....	....	....	....	....	....	....	G								
? elegans	....	....	....	....	....	....	....	....	....	....	....	....	....	[18]								
sp. nov. near euodus	....	....	....	....	L	....	....	....	....	....	L											
extensus																						
extenuatus																						
hirundo (=constrictus)	....	H	G																			
indentus	M	....	G																			
murchisoni furcillatus	....	....	....	A																		
nitidus	M																					
patulus	M	....	L G																			
pennatulus																						
perflexus	....	....	....	....	....	....	....	G														
? rectus	....	....	....	....	....	....	....	....	....	....	....	....	....	[18]								
sagitticaulis	....	....	....	....	....	....	....	....	....	....	....	L	....	×	G							
serratulus	....	....	....	....	....	....	....	....	....	....	....	....	....	×	G	....	....					
similis	....	....	....	....	H												Wh[30]					

ORDOVICIAN—*Continued.*

Genus and Species	Lower												Middle [10]				Upper [12]					
	Calciferous [1]								Chazy [11]					Lower *Dicellograpsus* Zone	Upper *Dicellograpsus* Zone		Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones																
	St. John Group (summit) [2]	Gros Manle [3]	Main Pt. Levis Zone [7]	Miscellaneous [4]	Phyllograptus anna Zone [5]	Pt. Levis [1]	Arkansas	Nevada [1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.	Trenton Limestone	New York and Canada	Arkansas [13]	Cove Fields, etc. [14]	Magog, Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Didymograpsus—*cont'd.*																						
cf. superstes	....	....	....	....	....	....	....	....	....	....	....	....	....	L								
spp. nov.	....	....	....	....	....	....	? G	....	....	....	....	....	....	L								
sp. ("nar. thread like")	M																					
sp.? ("very nar.")	M																					
Clematograptus multifasciatus	....	....	....	....	....	....	....	....	....	....	....	....	....	H L								
Nemagrapsus capilaris [8]	....	....	....	....	....	....	....	....	....	....	....	....	....	LG [15]								
Stephanograptus crassicaulis	....	....	....	....	....	....	....	....	....	....	....	....	....	G								
exilis	....	....	....	....	....	....	....	....	....	....	....	....	....	L G								
gracilis	....	....	....	....	....	....	....	....	....	....	....	....	....	×	G							
surcularis	....	....	....	....	....	....	....	....	....	....	....	....	....	× G								
New form allied to Stephanograptus	....	....	....	....	....	....	....	....	....	....	....	L	....									
Amphigraptus divergens	....	....	....	....	....	....	....	....	....	....	....	....	....	G								
Stenograptus (Lapworth *MS.*[6]) speciosus (Lapworth *MS.*[6])	....	....	L G	....	....	....	....	....	....	....	....	....	....									
Leptograptus annectans	....	....	....	....	....	....	....	....	....	....	....	....	....	....	? G	....	....	W G	....	?		
flaccidus	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	H	? G		
subtenuis	....	....	....	....	....	....	....	....	....	....	....	....	....	× G								
? macrotheca	....	....	G	....	....	....	....	....	....	....	....	....	....									
Azygograptus ? walcotti	....	....	....	....	....	....	....	....	....	....	....	....	....	? L G								
Dicellograpsus anceps	....	....	....	....	....	....	....	....	....	....	....	....	....	A		L						
divaricatus	....	....	....	....	....	....	....	....	....	....	....	....	....	×	G							
elegans	....	....	....	....	....	....	....	....	....	....	....	....	....	....	? G							
forchhammeri	....	....	....	....	....	....	....	....	....	....	....	....	....	A [16]								

ORDOVICIAN—*Continued.*

Genus and Species	Lower													Middle [12]				Upper [12]					
	Calciferous [1]								Chazy [11]						Lower *Dicellograpsus* Zone		Upper *Dicellograpsus* Zone		Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones																		
	St. John Group (summit) [2]	Gros Maule [3]	Main Pt. Levis Zone [3]	Miscellaneous [4]	Phyllograptus anna Zone [5]	Pt. Levis [1]	Arkansas	Nevada [1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.	Trepton Limestone	New York and Canada	Arkansas [13]	Cove Fields, etc. [14]	Magog, Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Dicellograpsus—*cont'd.*																							
gurleyi [17]	....	....	..	....	....	....	....	....	....	....	....	....	....	L G									
intortus	....	....	....	....	....	....	....	....	....	....	....	....	....	L	G								
" polythecatus	....	....	....	....	....	....	....	....	....	....	....	....	....	G									
rigidus	....	....	....	....	....	....	....	....	....	....	....	....	....	....	G								
sextans	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	? [20]					
" tenuibrachiatus (*nom. nud.*)	....	....	....	....	....	....	....	....	....	....	....	....	....	L									
Dicranograptus																							
cf. clingani	....	....	....	....	....	....	....	....	....	....	....	....	....	A									
dissimilaris	....	....	....	....	....	....	....	....	....	....	....	....	....	[18]									
furcatus	....	....	....	....	....	....	....	....	....	....	....	....	....	×									
? inequalis	....	....	....	....	....	....	....	....	....	....	....	....	....	[18]									
nicholsoni	....	....	....	....	....	....	....	....	....	....	....	....	....	? A	....	....	....	G	L				
" arkansasensis	....	....	....	....	....	....	....	....	....	....	....	....	....	....	G	....	G						
" whitianus [19]																							
" parvangulus	....	....	....	....	....	....	....	....	....	....	....	....	....	....	G								
" diapason	....	....	....	....	....	....	....	....	....	....	....	....	....	G									
ramosus	....	....	....	....	....	....	....	....	....	....	....	....	....	×	G	....	G	WhG	....	?G			
" rectus	....	....	....	....	....	....	....	....	....	....	....	....	....	L									
" spinosus (*nom. nud.*)	....	....	....	....	....	....	....	....	....	....	....	....	....	L	....	L							
" tardiusculus (*nom. nud.*)	....	....	....	....	....	....	....	....	....	....	....	....	....	L	....	? L							
Climacograptus																							
antiquus	....	....	....	....	....	....	....	—	....	....	—	—	....	L	G	....							
bicornis	....	....	....	....	....	....	....	....	....	....	....	?L	....	×	G	L	G	WhG					
caelatus [9]	....	....	....	....	....	....	....	L G	....	....	L	....	....										
caudatus	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	G						
" laticaulis	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	G						
cf. confertus	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	A							
kamptotheca	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	G						
oligotheca	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	G						
phyllophorus [21]	....	....	....	....	....	....	....	....	....	....	....	....	....	G									

ORDOVICIAN—*Continued.*

Genus and Species	Lower													Middle [12]					Upper [12]							
	Calciferous [1]								Chazy [11]						Lower *Dicellograpsus* Zone		Upper *Dicellograpsus* Zone		Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones																				
	St. John Group (summit) [2]	Gros Maule [3]	Main Pt. Levis Zone [1]	Miscellaneous [4]	Phyllograptus anna Zone [5]	Pt. Levis [1]	Arkansas	Nevada [1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.	Trenton Limestone	New York and Canada	Arkansas [13]	Cove Fields, etc. [14]	Magog, Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Climacograptus—*cont'd.*																										
scalaris [9]																										
scharenbergi														L G		L	G									
typicalis																		G		U G						
wilsoni																	G									
Diplograpsis																										
angustifolius						—	—	—			—	—	—	—	—	—	—	—	—		—			—		—
dentatus											L			×	G											
euglyphus						G	G					L		LG		? L		[29]								
foliaceus											L			×	G	L	G	Wh G							? G	
" *mut.* amplexicaule										G			HG													
" basilicus (*nom. nud.*)																L										
" confertus (*nom. nud.*)																L										
" *mut.* laciniatus														[18]												
" platydens (*nom. nud.*)																L										
foliosus														[18]												
"folium His. (as of Nicholson)" [10]																										
hudsonicus [20]																										
inutilis						G																				
latior (*nom. nud.*)																										
peosta [22]																										A
" *mut.* perexcavatus																					G					
putillus [22]														LA			? G									
quadrimucronatus																					G					
ruedemanni Gurley, sp. nov.																			H							
stenosus																		G								
trifidus [23]																		G								
truncatus															G											
whitfieldi																		? L	? G							
sp.								G						G	G											

ORDOVICIAN—*Continued.*

Genus and Species	Lower											Middle [12]				Upper [12]					
	Calciferous [1]							Chazy [11]					Lower *Dicellograpsus* Zone		Upper *Dicellograpsus* Zone	Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones															
	St. John Group (summit) [2]	Gros Maule [3]	Main Pt, Levis Zone [1]	Miscellaneous [4]	Phyllograptus anna Zone [5]	Pt. Levis [1]	Arkansas	Nevada [1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.	Trenton Limestone	New York and Canada	Arkansas [13]	Cove Fields, etc. [14]	Magog, Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Cryptograptus																							
antennarius	....	....	....	....	....	....	—	—			—	—	....	—	—	—	—						
tricornis	....	....	....	....	....	....	G	G	....	G	L	L	....	×	G	L	G						
Lasiograptus																							
bimucronatus	....	....	....	....	....	....	....	....	....	....	....	....	....	—	—		—						
mucronatus	....	....	....	....	....	....	....	....	....	....	....	....	....	L									
Glossograpsus														×	G	....	G						
arthracanthus	....	....	....	....	....	....	....	—		—	—		....	—	—								
ciliatus	....	....	....	....	....	....	....	L G	....	....	L	L	....	[18] G	L	G							
setaceus	....	....	....	....	....	....	....	....	....	....	....	....	....	[18] H	G								
spinulosus	....	....	....	....	....	....	....	....	....	....	L	....	....	—					—				
Reteograptus	—																		H				
eucharis	....	....	....	....	....	....	....	....	....	....	....	....	....	×	G								
geinitzianus	....	....	....	....	....	....	....	....	....	....	....	....	....	—									
tentaculatus	? M													L									
Trigonograpsus			?			—	—								—		—						
ensiformis	....	....	? G	....	....	G	G																
Clathrograptus														—									
cuneiformis	....	....	....	....	....	....	....	....	....	....	....	....	....	L									
Dendrograptus															—		—	—		—			
arundinaceus [24]	....	....	....	....	....	....	—	....	....	....	....	....	....	....	....	....	....	H G		—			
compactus	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	W G					
diffusus																							
divergens																							
erectus																							
flexuosus																							
fruticosus																							
gracillimus	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	Lq			
gracilis																							
cf. serpens	....	....	....	....	....	....	G	....	....	....	....	....	....	....	....	....	....						
simplex	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	W G					

ORDOVICIAN—*Continued.*

Genus and Species	Lower													Middle [12]					Upper [12]						
	Calciferous [1]								Chazy [11]						Lower *Dicellograptus* Zone		Upper *Dicellograptus* Zone		Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones																		
	St. John Group (summit) [2]	Gros Maule [3]	Main Pt. Levis Zone [1]	Miscellaneous [4]	Phyllograptus anna Zone [5]	Pt. Levis [1]	Arkansas	Nevada [1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.	Trenton Limestone	New York and Canada	Arkansas [13]	Cove Fields, etc. [14]	Magog, Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Dendrograptus—*cont'd.*																								
striatus																								
tenuiramosus																		W G						
unilateralis																								
spp. indet. 3 (fragments)																	G							
Callograptus																	2 G							
elegans		H	G												1 G									
salteri		H	G																					
Dictyonema																								
grande																								
cf. homfrayi				A																				
irregulare						G																		
murrayi																								
neenah													35											
obovatum															G									
perexile	M																							
quadrangulare	M																							
robustum																								
spp. incert														G			G							
Desmograptus																								
macrodictyon			G																					
Ptilograptus																								
geinitzianus			G																					
plumosus			G																					
Thamnograptus																								
anna								G																
barrandi														× G	G		G							
capillaris														H										
typus														H G										
Inocaulis																								
arbuscula																				U				

ORDOVICIAN—*Continued.*

Genus and Species	Lower												Middle [12]				Upper [12]					
	Calciferous [1]							Chazy [11]						Lower *Dicellograpsus* Zone		Upper *Dicellograpsus* Zone	Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones																
	St. John Group (summit) [2]	Gros Maule [3]	Main Pt. Levis Zone [1]	Miscellaneous [4]	Phyllograptus anna Zone [5]	Pt. Levis [1]	Arkansas	Nevada [1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.	Trenton Limestone	New York and Canada	Arkansas [13]	Cove Fields, etc. [14]	Magog, Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Buthograptus [26]																						
laxus													H									
Protovirgularia																						
dichotoma														? G								
Corynoides																						
calicularis														A		L	G					
Dawsonia																						
acuminata																						
campanulata														A		A						
monodon			G																			
rotunda																						
tenuistriata																						
tridens			G																			
spp. 3 or 4 (Ulrich *MS*)																				U G [27]		
sp.														A								
Caryocaris																						
curvilatus			G					G														
oblongus			G																			
wrightii							G	l G														
Megalograptus																						
welchi [28]																				Mi		
Phycograptus																						
brachymera														G								
macromera														G								
laevis														G								

NOTES TO ORDOVICIAN TABLE.

× signifies range admitted by all observers.
A signifies *fide* H. M. Ami.
G signifies *fide* R. R. Gurley.
H signifies *fide* James Hall.
L signifies *fide* Charles Lapworth.
M signifies *fide* G. F. Matthew.
Mi signifies *fide* S. A. Miller.
U signifies *fide* E. O. Ulrich.
W signifies *fide* C. D. Walcott.
Wh signifies *fide* R. P. Whitfield.

[1] *Calciferous*—The table given here is the result of a study of a considerable quantity of material from four American localities, as follows:

(*a*) The Point Levis shales. Two collections were examined. The first—from the main zone—was a very large one, containing a number of characteristic species, among which *Dichograptus flexilis* and *Phyllograptus ilicifolius var.* were conspicuous. They occur in black shale.

(*b*) The second and smaller collection from the Point Levis shales was from a hard ringing iron-gray shale, lithologically quite different from the much softer, black shale of the first collection; locality, 1½ miles north of the East Railway Station, Levis, Canada. As will be seen from the table, the fauna was strikingly different from that found in the softer, black shale. It was remarkable not so much for the species present (though the *Diplograpsidæ* seem highly characteristic), *as for those absent*. Indeed, it is hardly possible to examine a fragment of the black shale without finding a number of species which appear never to occur in the hard gray shale.

Analogy with British stratigraphy suggests that the difference is one of horizon and this view is reinforced by an examination of collections from the Calciferous beds in Nevada and Arkansas, the fauna of which agrees in a general way with that of the hard, gray Point Levis shale, and differs widely from that found in the black shale in the same locality. Further, as in Europe, so in Nevada, *Didymograpsus bifidus* marks a distinctly higher horizon.

Perhaps intermediate faunas (implying intermediate horizons) may exist. Some of those given by Ami appear to indicate that such is the case (see below), but I think the main divisions will not thereby be obscured. The species whose horizons are indicated in the table are those which I have myself identified. The exact ranges of the others are unknown, being merely Calciferous generally.

(*c*) A large collection from the Piñon Range, at the crossing of the Eureka and Palisade Railroad, at Summit, Nevada; collector, C. D. Walcott. This collection shows some very interesting and unique features, notably, the presence of *Phyllograptus* entirely unaccompanied by any traces of *Tetragrapsus* or more highly compound dichograptid genera, the presence of *Climacograptus* and *Glossograpsus*, and the extreme profusion of individuals of *Caryocaris* which amount to more than half the entire number of specimens.

(*d*) A rather small collection from Arkansas, in which, however, a number of Calciferous species could be made out.

From a general survey of the above collections, we may, I think, suspect that several species imply a higher horizon than the main (*Dichograpsus flexilis*) zone. I should at present name here (questioningly): *Phyllograptus anna*, the *Diplograpsidæ* generally, *Glossograpsus*, *Dictyonema irregulare*, *Thamnograptus anna*.

That this classification by no means exhausts the zone problem of our Calciferous, may be inferred from the fact that other collections imply in the peculiar association of species exhibited at least two other horizons. On them I am not, however, at present prepared to report in detail, and will only say that in one *Phyllograptus typus* (which seems to be absent from the main zone, the genus being there represented by great numbers of *P. ilicifolius mancus*, Lapw. *MS.*), is the dominant species, and that the other is characterized mainly, if not almost entirely by several *Dictyonema* species which are absent from the main Point Levis zone. This last feature (that the zones are for the most part *mutually complementary*) is a striking and important one.

Finally, I may say that the table here given, classifies every species, I believe, ever recorded, except certain faunas reported by Mr. Ami (in Ells, Ann. Rep. Geol. Surv. Can. for 1887 (1889), Pt. K). The twelve Calciferous faunas reported were not classified into zones. Careful study of them leads me to think that they harmonize fairly well with the division here suggested, viz., into a lower zone rich in (especially dichograptid) species, and an upper zone with a much less rich fauna in which the diplograptid element is conspicuous.

Newly introduced species whose horizon is not clearly defined are listed in the miscellaneous column.

[2] Stage *d* of Division 3 of Matthew (reference, Note 2, Cambrian table).

[3] Tabulated from Hall (Canad. Org. Rem., Dec. II., 1865, pp. 68–142).

[4] See last paragraph of Note 1.

[5] Tabulated from Hall (*loc. cit.*, in Note 3, above), and from Lapworth (Trans. Roy. Soc. Can., 1886, V., Sect. IV., p. 184).

[6] Identification by Lapworth from specimens sent (in *MS.* report to author).

[7] From a loose bowlder.

[8] This species *fide* Ami (Bull. Geol. Soc. Amer., 1891, II, table p. 495), occurs in the Calciferous. On p. 492 (the only list in the paper which contains this species), to the specific diagnosis is added a "?" In this connection I may say that I identified a specimen in the Nevada collection (the same horizon) as *capilaris* Emmons, but later, after obtaining Emmons' species at Stockport, found the Nevada specimen to be *Thamnograptus anna* Hall.

[9] The form found by Mr. Ami (Ann. Rep. Can. Surv. for 1887 (1889), p. 50K) in the (upper) Calciferous, and referred by him to *Climacograptus scalaris* Hisinger, is in all probability, this species. It could not be *C. scalaris*, inasmuch as that species is nowhere else found below the very summit of the Ordovician (Brachiopod schists of Sweden; and, as var. *normalis* Lapw., at base of Upper Silurian in Britain). See also note 21.

[10] This species, listed by Ami (in Ells, *loc. cit.*, p. 50K), can hardly be *Cephalograpsus folium* His., as that species is known only in the highest beds of the Ordo-

vician (Upper Graptolite schists of Sweden). In the Upper Calciferous shales of Nevada, many specimens of *Phyllograptus* occur, some of which, not being well enough preserved to show all the *Phyllograptus* structure, present a deceptive *folium* aspect. Whether this is the explanation of Ami's *folium* or not I cannot say, as I have not seen the specimens.

[11] *Chazy.*—Little is known in regard to the graptolite fauna of this horizon. In Nevada, *Didymograpsus bifidus* Hall, occurs in strata certainly supra-Calciferous and probably Chazy horizon (*fide* oral statement of C. D. Walcott.)

In a small collection from the Chazy at Mystic, Canada, a few poorly preserved (mostly fragmentary) graptolites were seen. Only *Diplograpsis foliaceus* Murch. (*mut. amplexicaule* Hall), and *Cryptograptus tricornis* Carr., could be determined with any certainty. Some *Didymograpsus* fragments of two species completed the collection.

Further, somewhere between the *Dichograpsus* fauna characteristic of the Calciferous, and the *Dicellograpsus* faunas, characteristic of the (certainly pre-Utican and probably) Trenton, are to be placed the faunas occurring in the beds at Kicking Horse (Wapta) Pass, Rocky Mountains (Lapworth, 1886, Ann. Rep. Geol. Surv. Can., II., pp. 22D–24D; also Science, 1887, IX., p. 320), and those along Dease River, British Columbia (Lapworth, 1889, Ann. Rep. Geol. Surv. Can., III., pp. 94B, 95B; also Can. Rec. Sci., III., pp. 141, 142). Approximately at least, these beds are of the same age, and in a general way, and as a diagnosis by exclusion, may be said to be Chazy.

[12] *Trenton-Lorraine.*—Besides faunas already recorded, the following collections have been studied:

Lower *Dicellograpsus* zone; Lower Falls, Kinderhook Creek, near Stockport, N. Y. About three tons of excellent material collected by the author. Also a rather small collection from Schodack Landing, N. Y.

Upper *Dicellograpsus* zone: Large collection from Magog, Canada.

Graptolite Zones.—As remarked by Lapworth (Trans. Roy. Soc. Can for 1886, V., Sec. IV., p. 176), the Trenton limestone should, in all probability be regarded as a deep-water deposit. Its age not improbably embraces both the Lower and Upper *Dicellograpsus* zones. Briefly the evidence is:

(*a*) At Schodack Landing, Rensselaer county, N. Y., Ford (Amer. Jour. Sci., 1884, XXVIII., p. 206) found the Lower *Dicellograpsus* fauna associated with a brachiopod fauna which, as regards age, may be anywhere from Trenton to Lorraine, but cannot be pre-Trenton.

(*b*) In spite of assertions to the contrary, the graptolite faunas of the *Dicellograpsus* zones are not only identical with, but are strongly contrasted to those of the Utica shale proper (that of the Mohawk Valley). And Lapworth's statement that, with the asserted exception of five species, not a shadow of palæontological evidence has yet been adduced to show that these Norman's Kill or Marsouin rocks are newer than the Trenton," is fully justified (*loc. cit.*, p. 171).

(*c*) Parallelism with European (principally British) stratigraphy, strongly confirms the order of superposition suggested by the faunas, viz., in ascending order:

Lower Dicellograpsus zone } = Trenton (?)
Upper Dicellograpsus zone }
Utica.

If now the *Dicellograpsus* zones cannot be pre-Trenton, and must be sub-Utican, by exclusion they only can only be Trenton, and as a rough approximation we may say lower and middle Trenton respectively. Following them, of course, are the Utica and Lorraine horizons.

[13] Contrary to the opinion formerly expressed as the result of insufficient study, the Arkansas beds belong rather to the Lower than to the Upper *Dicellograpsus* zone. To show this, the following table is given showing the range of the species as ascertained in New York and Canada:

Arkansas Species	Lower Dicellograpsus Zone	Upper Dicellograpsus Zone	Utica	Supra Utican
Didymograpsus sagitticaulis	×			
" serratulus	×			
Stephanograptus gracilis	×			
Leptograptus (like annectans)				
Dicellograpsus rigidus	Gl			
" divaricatus	×			
" intortus	×			
" elegans	Var.	LH	UH	
Dicranograptus ramosus	×	×	×	
" nicholsoni			×	
" " parvangulus				
" " arkansasensis		×		
Climacograptus antiquus ?	×	Var.		
" bicornis	×	×	×	
Diplograpsis foliaceus	×	×	×	×
" trifidus				
" whitfieldi	×			
" angustifolius	×			
Cryptograptus tricornis	×	×		
Lasiograptus mucronatus	×	×		
Glossograpsus ciliatus	×			
Dictyonema obovatum				
Dendrograptus sp				
Thamnograptus barrandi	×	×		

The following abbreviations mean: Gl. Glenkiln; LH. Lower Hartfell; UH. Upper Hartfell. The species so marked are known in America only in Arkansas, and the comparison is with their ascertained foreign range in strata equivalent to those represented in the column.

[14] Zone first noted by Lapworth (Trans. Roy. Soc. Can. for 1886, V., Sec. IV., p. 172), as "Zone without *Coenograptus gracilis*." The collections referred here were from the Cove Fields, from St. John Market, Quebec, and from the north side of the Island of Orleans. Subsequently Ami (Ann. Rep. Geol. Surv. Can. for 1887, p. 46K), found *Stephanograptus* ("*Coenograptus*;" species not stated) in this zone.

[15] In the black shales of the Lower *Dicellograptus* zone in the Hudson Valley, I have found typical specimens of this species. I believe it does not occur at other horizons. Ami (Ann. Rep. Geol. Surv. Can. for 1887, p. 53K ; consult also 51K, where the same zone appears to be represented), reports it, however, from a horizon certainly Calciferous, and apparently Upper Calciferous. (See also Note 8.)

[16] It is doubtful whether this is Geinitz's species. More probably it is referable to the next, as there appears to be but one species closely allied to Geinitz's at this horizon, and that one Prof. Lapworth (*MS.* report to author) says is distinct. *Cf.* next.

[17] Probably Ami's *D. forchhammeri* is this species. *Cf.* preceding note.

[18] As suggested by Lapworth (Geol. Distrib. Rhabdophora, p. 31), the following species described by Emmons (*American Geology*, 1856. Pt. 2, pp. 104–111), are probably referable to this zone.

Didymograpsus ? ("Monograpsus") elegans Emm.
" ? ("Monograpsus") rectus Emm.
Dicranograptus ? ("Cladograpsus") inequalis Emm.
" ("Cladograpsus") dissimilaris Emm.
Diplograpsis foliaceus Murch.
(as D. dissimilaris Emm.)
(as D. rugosus Emm.)
(as D. obliquis Emm.)
(as D. laciniatus Emm.)
foliosus Emm.
Glossograpsus arthracanthus.
" setaceus Emm.

Further, Didymograpsus ? ("Monograpsus") rectus Emm., from "Columbia county (N. Y.), in the Taconic Shales," probably belongs at this horizon, which is very well developed in Columbia county. The species presents every appearance of an accidental juxtaposition of two fragments.

[19] As an appendix to the table, the following fauna reported by Dr. C. A. White, (Rep. Wheeler Surv, 1875, IV., pp. 62–66), from strata five miles north of Belmont, Nevada, may be noted. The identifications have been made after a study of the types in the National Museum. As far as the stratigraphic value of the species is concerned, the horizon might be anywhere from the Lower Dicellograpsus zone to the Utica, both inclusive.

White's Name	Identification
Graptolithus (Climacograptus) ramulus.	Dicranograptus nicholsoni whitianus.
Graptolithus (Diplograptus) pristis Hall ?	Diplograpsis foliaceus.
Graptolithus (Diplograptus) hypniformis.	Diplograpsis foliaceus ?
Graptolithus (Diplograptus) quadrimucronatus.	Diplograpsis sp.?

[20] From a loose slab carried from its original site by commerce ; age, "the Hudson River Group."

[21] The "*Climacograptus scalaris*, Hisinger, var. *normalis*, Lapworth," of Ami (Ann. Rep. Geol. Sur. Can. for 1887 (1889), p. 78K ; Bull. Geol. Soc. Amer., 1891, II., p. 496), is almost certainly this species, as this is the only one at this horizon to which it could refer. Hall's *scalaris* of 1847 consists of four species. *Cf.* Note 9.

[22] "Hudson River Group of Iowa" (Hall).

[23] Cf. *D. foliaceus calcaratus*, Lapw. (in Armstrong, Young & Robertson's Cat. West Scottish Foss., p. 6, Pl. II., Fig. 30.) The latter is a Hartfell species. The identity of the two forms can hardly be asserted at present as Lapworth's *calcaratus*, rests solely upon the figure of a basal fragment. Still, had I had access to his figure, I should not have described *D. trifidus*.

[24] Entirely overlooked by cataloguers. Horizon, from label on type in American Museum of Natural History, New York City. Locality, Turin, Lewis county, N. Y.

[25] Trenton Limestone of Wisconsin.

[26] I suspect that, as Prof. Whitfield (Mem. Amer. Mus. Nat. Hist., N. Y., 1895, I., pp. 40–41) believes, this genus is non-graptolitic.

[27] One species from the Trenton of Minnesota; three species from the Cincinnati group at Cincinnati, Ohio; all in the collection of Mr. Ulrich.

[28] "Lower beds, Cincinnati Group" (Ulrich; label).

[29] *Diplograpsis ruedemanni* Gurley, sp. nov.

(*Diplograptus pristiniformis*, Ruedemann, 1895, Amer. Jour. Sci., pp. 453–455, Figs. 2, 3; *Diplograpsis ruedemanni* Gurley, *nom. nud.*, supra, p. 78).

Entire polypary consisting of a number of diprionidian stems ("polyparies" as formerly understood) originating in and radiating from a common central "disk" (Ruedemann). Diprionidian stems quite small, the greatest length observed (in incomplete specimens) 7^{mm}. Maximum breadth 1.5^{mm} (a single stout specimen reached 1.75^{mm}). Thecæ cylindrical, the breadth practically the same throughout and their axis practically straight; 38–50 in 25^{mm} as nearly as determinable (ranging from 2 in 1^{mm}, 7 in 4^{mm}, 5 in 3^{mm}, to 3 in 2^{mm}). Aperture in scalariform impression, squarish, $0.6–0.8^{mm}$ on a side; margin straight, in the large majority of specimens appearing perpendicular to virgula, thus producing a deep indentation, a shorter overlap ($\frac{1}{4}$–$\frac{1}{2}$), and an acute "denticle." But I believe (the material not perfectly satisfactory) that the real condition is: margin inclined to virgula on proximal ("distal") side about 60° (say 55°–65°), and an overlap of ½. Inclination of the thecæ on proximal ("distal") side to virgula, 40°.

I know but six Diplograpses with as many thecæ in 25^{mm}, viz.: *D. sinuatus* Nich., and *D. insectiformis* Nich., both Upper Silurian species; *D. confertus* Nich., whose breadth (8^{mm}) alone suffices to exclude it: *D. putillus* (Hall), which has 34–38 thecæ in 25^{mm} without overlap; *D. minimus* Carr., with which the present species will bear comparison; and *D. hudsonicus* Nich. From the last *D. ruedemanni* differs in the form and amount of overlap of the thecæ and in lacking the spine on the lower lip of the aperture.

Horizon and locality.—Utica Shale, near Dolgeville, N. Y., dedicated to the discoverer, Dr. R. Ruedemann, of Dolgeville.

[30] *Fide* Whitfield (Rep. Wheeler Surv., 1875, IV., p. 19). I do not believe these genera occur in the Utica, and think with Lapworth, that the *Didymograpsus* was probably a *Leptograptus*. As in Britain the Glenkiln, so in America its equivalent, the Lower *Dicellograpsus* Zone, seems to mark the last appearance of the genus *Didymograpsus*.

SUPRA-ORDOVICIAN

Genus and Species	Upper Silurian		Devonian		Lower Carbon.
	Clinton	Niagara	Upper Heldbg.	Hamil-ton	Choteau
Diplograpsis? dubius[1]	SG				
Lomatoceras[2]	—				
clintonense	H G				
convolutum coppingeri[3]					
Gladiolites[4]	—				
venosus	HG				
Dendrograptus		—			
dawsoni		S			
dubius		S			
frondosus		S			
novellus		HG			
praegracilis		S			
ramosus		S			
spinosus		S			
Callograptus		—			
granti		S			
minutus		S			
multicaulis		S			
niagarensis		S			
Dictyonema	—	—	—	—	—
blairi					G
expansum		SG			
fenestratum			H		
gracile		S			
actinotum				HG	
pergracile		S			
pertenue	F				
retiforme		S			
scalariforme	F				
splendens					
tenellum		S			
websteri					
Desmograptus				—	
devonicus				HG	
Calyptograpsus		—			
cyathiformis		SG			
micronematodes		SG			
?radiatus		S			
subretiformis		SG			
Rhizograpsus		—			
bulbosus		S			
Acanthograpsus		—			
granti		SG			
pulcher		SG			
Inocaulis		—			
anastomotica		R			
bellus		HW			
cervicornis		SG			
diffusus		SG			

SUPRA-ORDOVICIAN—*Continued*

Genus and Species	Upper Silurian		Devonian		Lower Carbon.
	Clinton	Niagara	Upper Heldbg.	Hamilton	Choteau
Inocaulis—*cont'd.*					
divaricatus		H			
phycoides		SG			
plumulosus		HSG			
?problematicus		S			
ramulosus		S			
walkeri		SG			
Thamnograptus		?			
?bartonensis		SG			
Ptilograptus		—			
foliaceus		SG			
Cyclograptus		—			
rotadentatus		SG			

NOTES TO SUPRA-ORDOVICIAN TABLE.

F signifies *fide* A. F. Foerste.
G signifies *fide* R. R. Gurley.
H signifies *fide* James Hall.
HW signifies *fide* James Hall and R. P. Whitfield.
R signifies *fide* E. N. S. Ringueberg.
S signifies *fide* J. W. Spencer.

[1] I have examined a number of specimens of Spencer's *Phyllograptus dubius*. It is found merely as a black stain on the dark brown weathered Clinton shales. In regard to it I am willing to say only that the specimens appear to be mostly, and probably are entirely, Diplograptids. At least two (perhaps three or even more) species are present, as I found one which had the thecæ about 1^{mm} apart, and another about 1.5^{mm}. All the marginal fringing (which imparts somewhat the aspect of an *Inocaulis* branch) is due to weathering.

As regards the genus, there is little certainty, the specimens being very indistinct. *Phyllograptus*, of course, it cannot be and the present generic reference will probably prove to be the correct one.

[2] See p. 79.

[3] From Arctic America.

[4] See p. 79.

[5] Only two authors have, I believe, touched on the possible presence of Graptolites in the Carboniferous. Portlock (Geol. Rep. Londonderry, etc., 1843, pp. 321, 322) says: "The family of Graptolites has at present no known representative in the Carboniferous system; although a specimen from the mountain limestone, belonging to Captain Jones, M. P., has a strong resemblance to some of the double Graptolites."

And Hall (Pal. N. Y., 1859, III., p. 496) remarks that:

"The Graptolitidæ are therefore at this time clearly traced to the base of the Carboniferous system, and we may probably find allied genera to the close of the Palæozoic period."

In a collection presented to the U. S. National Museum, by Mr. R. A. Blair, of Sedalia, Mo., a *Dictyonema* was pointed out to me by Mr. Charles Schuchert, Curator of Palæontology. I have elsewhere described it as *D. blairi*. Associated with it are some poorly preserved specimens which bear, as Portlock would say, "a strong resemblance to some of the double Graptolites." I am, however, inclined to think it only a superficial resemblance, and pending further collections can assert the existence of no graptolite fauna other than *D. blairi*. Concerning that species there is no room for doubt.

COMPOUND AND SIMPLE FORMS IN THE DIPLOGRAPSIDÆ.

The recent paper of Ruedemann[1] unquestionably marks a real advance in our knowledge of *Diplograpsis* structure. Although I have not seen the specimens, I am prepared to accept the results described, as several years ago I saw a similar specimen on which a good many individuals of *Diplograpsis foliaceus* Murch., were so grouped as, on the doctrine of probabilities, to render it almost certain that they must have grown radiatingly from a common center. The specimen did not, however, show the common center. Since then I have seen a similar specimen in Professor Hall's collection which is still less equivocal. With better material Ruedemann has given a very interesting description of the structure, and has I think proved at least the following: That in two *Diplograpsis* species the stems ("polyparies," as we have been calling them) formerly regarded as simple and complete in themselves, are in reality only fragments of compound aggregates, relative to whose center the so-called "distally prolonged virgula" is in reality proximal, and the position of the sicula distal.

Such a discovery is to a certain extent revolutionary of our views of diplograptid structure, and is in importance comparable only to Hall's similar discovery of central connections for many of the numerous fragments previously lumped together as Monoprions and Monograpti on the easy "cells-on-one-side" character.

But (and this is the principal *raison d'etre* of this section) it seems to the writer that induction from these two *Diplograpsis* species to the *Diplograpsidæ* in general may be premature. And it is to the generalizations that Ruedemann has made (and very properly, indeed, from the standpoint of his material alone) that attention is directed.

The real question seems to be the magnitude of the taxonomic value of the discovery. In two *Climacograptus* species (*C. caelatus*, *C. phyllophorus*)

[1] Amer. Jour. Sci., 1895, pp. 453–455, Figs. 1–5.

an organ which from its position and character must be regarded as homologous with Ruedemann's "central disk" occurs. But in these species the "disk" is almost certainly simple, as it has a perfectly definite, uniform and constant outline. The compound form cannot then be taken as a family character. It may, however, prove of generic rank, *Diplograpsis* perhaps being distinguished by a compound, and *Climacograptus* by a simple disk. While it could be conceived as not even having this value, it seems to me not improbable that it may ultimately acquire this significance.

R. R. GURLEY, M.D.

U. S. GEOLOGICAL SURVEY.

STUDIES FOR STUDENTS.

DEFORMATION OF ROCKS.—II. AN ANALYSIS OF FOLDS.

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Complex folds.
- Origin of complex folds.
- Character of complex folds.
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As ordinarily treated, folds are considered as simple flexures in two dimensions. As they occur in nature, folds are complex flexures in three dimensions.

Folds in rocks may be compared with the waves of the sea. Each large wave has superimposed upon it waves of the second

order; upon these are waves of the third order, and on these waves of the fourth order, and so on. Moreover, running across the most conspicuous waves at various angles up to perpendicularity may be other waves of an equally composite character. As observed from a ship at sea the waves of the first order are so large and have such gentle slopes that they are often overlooked, while the steeper waves of the second order are noticed, because more conspicuous. On account of their small size the waves of a higher order than the second are usually unnoticed, as are also the waves of all orders which are transverse to the more conspicuous set.

If when stirred by a great storm the surface of the sea could in an instant be frozen, we should obtain some idea of the complexity of the waves. We should see primary elevations and depressions of circular, oval, and lenticular horizontal sections, in different sets, crossing one another in various directions, and upon these would be other sets of waves of like complexity of the second, third, and fourth orders, and so on.

The rock waves of the earth are of greater size and of equal or greater complexity than the waves of the sea. The rollers of the sea, when not wind forced may be compared with the long, gentle folds of rock. At first sight they seem simple, but, like the rock folds, when observed closely they are found to possess secondary crenulations. At the other extreme are the highly complex waves running in various directions at the same time, formed by the shifting winds of a great storm, by currents and tides together. The sea in this condition may be compared with the rocks in which each set of primary folds has superimposed upon them folds of the second order, and upon these those of a higher order to the *n*th order. The smaller orders of folds are microscopic. Such complex rock folds are called crumpled, plicated, or implicated.

In this comparison it is not meant to imply that the forces which produce rock folds are the same, or that they work in the same manner, as the forces which produce sea waves. Nor is it meant that the forms of the folds are the same as the forms of

the waves. The only purpose of the comparison is to give at the outset some idea of the complexity of rock folds.

Tangential thrust and gravity are assumed to be the causes of folds. No attempt will be made here to show this or to explain the cause of thrust, although in the last analysis it is probable that thrust is dependent upon gravity. At all times and in all positions rocks are subject to the force of gravity. Thrust and gravity act upon rocks of heterogeneous character. Rock heterogeneity, therefore, modifies the forms of folds. Folds are further modified by igneous rocks. In what follows, the effects of igneous rocks are at first excluded.

We shall now attempt to analyze the rock waves or folds. For convenience, they will first be considered in two dimensions.

SIMPLE FOLDS.

Simple folds are classified by de Margerie and Heim[1] as follows: A fold is upright or symmetrical when the axial plane is vertical, or nearly so, and the limbs have nearly equal dips in opposite directions at corresponding points (Fig. 1).

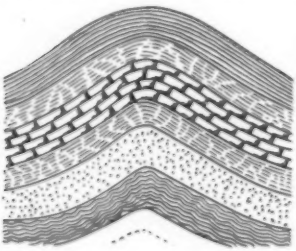

FIG. 1.—Simple upright fold.

A fold is inclined or symmetrical when the axial plane is inclined and the limbs have unequal dips in opposite directions at corresponding points (Fig. 2).

A fold is overturned or overfolded when the axial plane is inclined and the limbs have equal or unequal dips in the same direction at corresponding points (Fig. 3). An overturned fold is lying or recumbent when its axial plane is horizontal, or nearly so (Fig. 4). The different parts of an overturned fold are the arch limb, reversed limb, and trough limb (*a*, *b*, *c*, Fig. 4).

As to closeness of compression, folds are described by de

[1] Les dislocations de l'écorce terrestre, par EMM. DE MARGERIE et ALBERT HEIM, Zürich, 1888, pp. 49–63.

Margerie and Heim as follows: An ordinary fold is one in which the strata diverge from the crest of the anticline and the trough of the syncline (Figs. 2–4). Ordinary folds may be described as

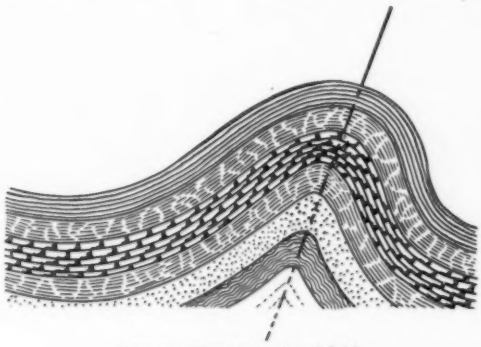

FIG. 2.—Simple inclined fold.

gentle, open, or close. In close folds, according to Willis, the process has gone so far that the strata are perceptibly changed in thickness in different parts of the fold. An isoclinal fold

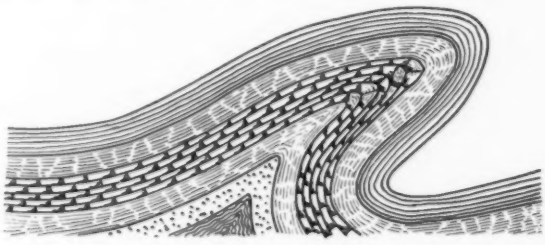

FIG. 3.—Simple overturned fold.

is one in which the strata are parallel, or nearly so (Fig. 5). A fan fold is one in which the strata converge downward from the crest of the anticline (Fig. 9), or upward from the trough of the syncline. In this case the strata at the limbs of the fold are always greatly thinned, and in some instances the central strata are absent, the material having flowed up and down, form-

ing detached arch cores and detached trough cores. An ordinary, isoclinal, or fan fold may be upright, inclined, or overturned.

In the formation of the simple fan-shaped anticline the

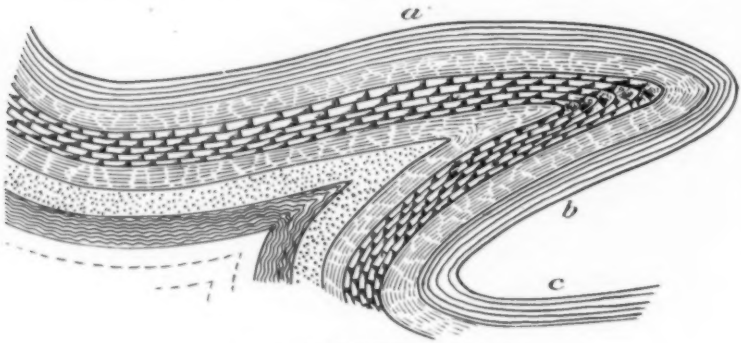

FIG. 4.—Simple recumbent fold.

rocks are extremely compressed on the limbs of the fold, while on the anticline the compression is not so severe. This is doubtless due to the partial escape from pressure of the material which

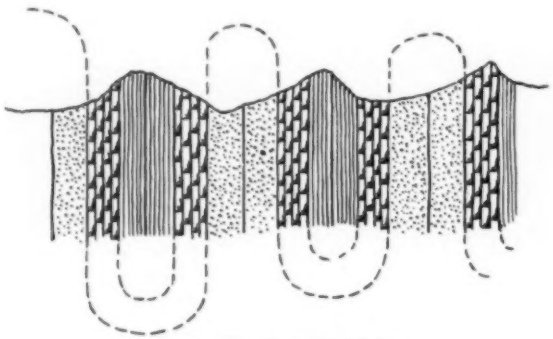

FIG. 5.—Simple isoclinal folds.

rises into an arch, as compared with the deeper-seated material in the limbs of the folds, which constitutes a part of the continuous crust of the earth in which the major thrust must have been transmitted. Another factor is the relative strength

of the layers. A strong stratum may deform weaker layers, geologically below, into the fan form by producing flowage in them. The formation of the fan fold may be further assisted

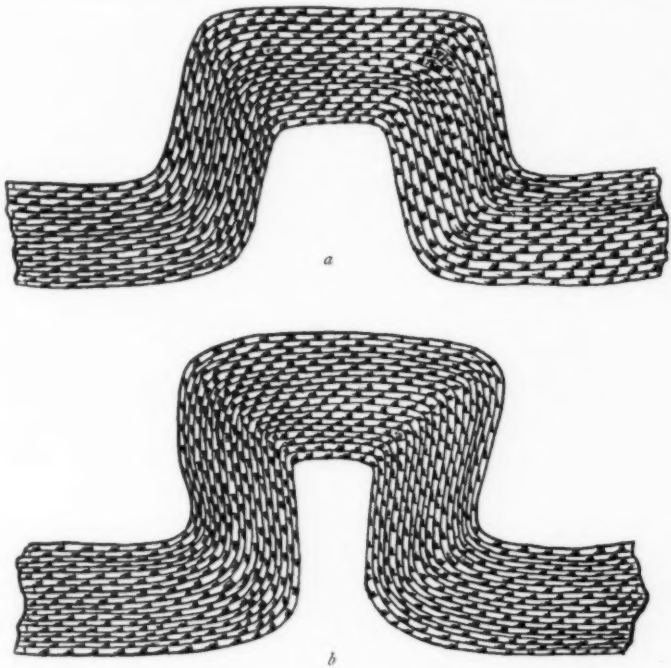

FIG. 6.—*a*, Diagram of fold in limestone of the Jura Mountains, showing hinge-like bending at sides of anticlines: *b*, the same somewhat more closely compressed, so that the fold has become fan-shaped.

by the tendency of rocks to bend farther at a place where deformed rather than to bend in a new place. The different phases of the formation of fan folds are illustrated in the Jura. In the folds of certain parts of the Jura one is impressed with the flatness of the anticlinal domes and the synclinal troughs, the steepness of the limbs, and the rapidity of the change from flat dips at the anticlines and synclines to nearly vertical dips on the

limbs of the folds (Fig. 6*a*). So quick is the change that the folds may be said to have corners, where the beds are bent in a circular fashion almost within their own radius. In the more closely compressed folds the beds constituting opposite limbs of the folds are overturned in opposite directions, thus producing a true fan fold (Fig. 6*b*). It is clear that the material of the domes partly escaped the thrusts which were transmitted in the solid rocks below. This thrust from both directions pressed the lower parts of the limbs closer and closer together, while the rigidity of the partly free dome above prevented the upper part of the legs from following, and thus the limbs were overturned in opposite directions. It is probable that the folds in the Jura represented by Fig. 6 were not very deeply buried, and that had the material been much deeper the more regular form of fan fold shown by Fig. 9, and characteristic of the Alps, would have been produced. It may be suggested that the Jura and the Alps belong to the same great geological province, and since the types of folding are the same in both mountain ranges it is not improbable that if the Jura were uplifted sufficiently and more deeply denuded the ordinary fan-shaped fold of the Alps would be revealed.

It follows from the above that the mechanics of the formation of fan-shaped synclines are not the same in all respects as those of the anticlines. It can hardly be assumed that synclines are of such magnitude that the lower parts reach a level in which the thrusts are less than at a higher level. In other words, it cannot be assumed that the lower part of the trough of a syncline is under less lateral compression than the center of the fold. This may, however, be the case if a "level of no strain" is so near the surface as two miles. Even if this supposed level is not at a greater depth than seven or eight miles, Davison's later estimate, the thrust may be considerably less at the deeper parts of the fold than at the places of greatest lateral force. We therefore do not know whether the first and probably the most important cause of the production of fan-shaped anticlines—difference in amount of thrust—may also apply to the produc-

tion of fan-shaped synclines. A difference in the strength of layers and a tendency for layers to continue to bend at certain places when bending has begun, rather than at other places, may tend to produce fan-shaped synclines. For instance, if a very strong layer is between two weaker layers, and this stronger layer becomes bent more decidedly at the outer, upper parts of the syncline, it may continue to bend at these places, and by its strength deform the softer material above and below it, so as to force the whole into a fan form. That minor fan-shaped synclines are thus produced is highly probable, but it may be doubted whether fan-shaped synclines of the first order would be thus formed, although they may be produced by differential thrust if the theory of a "level of no strain" be true.

COMPOSITE FOLDS.

The greatest flexures of the earth's crust are termed by Dana *geanticlines* and *geosynclines*. Generalizing from his illustrations, it appears that these may be defined as flexures which are predominantly due to the force of gravity in its tendency to produce isostatic adjustment. The deforming force is therefore mainly vertical. When rocks are subjected to strong lateral forces they are also deformed, and mountain ranges are produced. All folds, of whatever magnitude, thus made by the work of great lateral thrust and gravity combined, when not simple, are called, following Dana, *anticlinoria* and *synclinoria*. An anticlinorium or synclinorium of the first order of magnitude is one which comprises an entire mountain range. Illustrating this usage of the terms, the great geological province or basin of deposition of which the Jura, the great valley of Switzerland, and the Alps occupy a part, was a geosyncline. When subjected to orogenic forces the mountain ranges now seen were produced. The Alps and Jura, taken as wholes are anticlinoria of the first order, and the great valley between is a synclinorium of the first order.

The various kinds of simple folds may be united to produce a great variety of composite structures. A composite fold may be an anticlinorium or a synclinorium. An anticlinorium or

synclinorium, like a simple fold, may be upright, inclined, or overturned, but it is probable that in composite folds of the first order of magnitude the last rarely if ever occurs.

Taking as axial planes the radial planes of the primary fold, the secondary folds may be upright, inclined, or overturned, or on different parts of the same primary fold each form may occur. The radial positions of the axial planes give the proper basis in comparing the dynamic processes and effects of folding, but

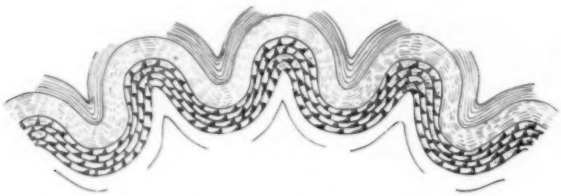

FIG. 7.—Ideal section of an upright normal anticlinorium.

because we rarely see the whole of a great anticlinorium or synclinorium at a single view, it is perhaps best to treat both the primary and secondary folds in reference to the plane of horizon.

Some of the special cases of composite folds are as follows:

NORMAL COMPOSITE FOLDS.

The upright normal anticlinorium.—The primary fold of the upright normal anticlinorium has a vertical or nearly vertical axial plane, and the limbs at corresponding points have nearly equal average dips in opposite directions.

(*a*) The primary fold is composed of a set of secondary folds each of which is upright or nearly so, taking the radial planes of the primary fold as axial planes of the secondary folds. Referring the axial planes to the horizon, at the crest of the anticline the secondary folds are upright, and in passing in either direction transverse to the primary axial plane the secondary folds are inclined, but not overturned. The two sets of secondary axial planes on opposite sides of the crest of the primary fold diverge upward and converge downward (Fig. 7).

(*b*) Composed fan fold. The primary fold is composed of a set of secondary folds which at the crown are upright, and in passing in either direction transverse to the primary axial plane the secondary folds are first inclined and then overturned. The secondary folds may be ordinary, isoclinical, or fan-shaped. The

FIG. 8.—Ideal composed fan fold.

two sets of secondary axial planes on opposite sides of the crest of the primary fold diverge upward and converge downward (Figs. 8 and 9). Often in extreme cases of compression at

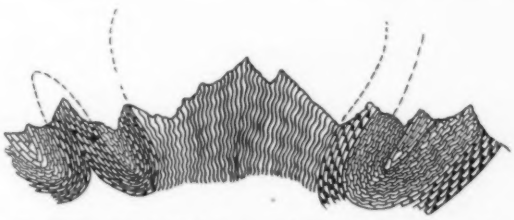

FIG. 9.—Generalized fan-fold of the central massif of the Alps. After Heim.

the crest of the primary anticline the secondary folds are fan-shaped, and passing in either direction these grade into isoclinal and then into ordinary folds. Such are many of the composite folds of the Alps.

The inclined normal anticlinorium.—The primary fold of the inclined normal anticlinorium has an inclined axial plane and the limbs at corresponding points have unequal average dips in opposite directions. The primary fold is composed of a set of secondary folds which are inclined or overturned. The two sets of secondary axial planes on opposite sides of the crest of the

primary fold diverge upward and converge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped.

The overturned normal anticlinorium.—The primary fold of the overturned normal anticlinorium has an inclined axial plane, and the limbs at corresponding points have equal or unequal average dips in the same direction. The primary fold is composed of a set of secondary folds, which are overturned in the same

FIG. 10.—Ideal section of an upright normal synclinorium.

direction as the primary fold. The two sets of secondary axial planes on opposite sides of the crest of the major fold diverge upward and converge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped.

The upright normal synclinorium.—The primary fold of the upright normal synclinorium has a vertical or nearly vertical axial plane, and the limbs at corresponding points have nearly equal average dips in opposite directions.

(*a*) The primary fold is composed of a set of secondary folds, each of which is upright, or nearly so, taking the radial planes of the primary fold as axial planes of the secondary folds. Referring the axial planes to the horizon at the trough of the synclinorium, the secondary folds are upright, and in passing in either direction transverse to the primary axial planes the folds are inclined, but not overturned. The two sets of axial planes on opposite sides of the trough of the major fold converge upward and diverge downward (Fig. 10).

(*b*) Inverted intermont trough.[1] The primary fold is composed of a set of secondary folds, which at the center of the trough

[1] Les dislocations de Pécorce terrestre, par EMM. DE MARGRIE et ALBERT HEIM p. 83. Zürich, 1888.

are upright, and in passing in either direction transverse to the primary axial plane the secondary folds are first inclined and then overturned. The two sets of secondary axial planes on opposite sides of the trough of the major fold converge upward and diverge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped (Fig. 11).

The inclined normal synclinorium.—The primary fold of the

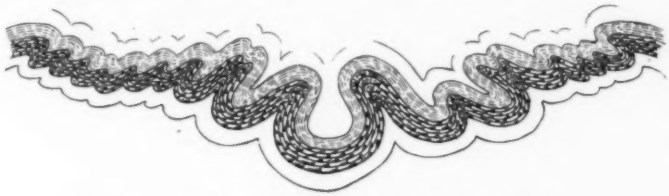

FIG. 11.—Ideal section of an inverted intermont trough.

inclined normal synclinorium has an inclined axial plane, and the limbs at corresponding points have unequal average dips in opposite directions. The primary fold is composed of a set of secondary folds, which are inclined or overturned. The two sets of secondary axial planes on opposite sides of the trough of the major fold converge upward and diverge downward. The secondary folds may be ordinary, isoclinal or fan-shaped.

The overturned normal synclinorium.—The primary fold of the overturned normal synclinorium has an inclined axial plane, and the limbs at corresponding points have equal or unequal average dips in the same direction. The primary fold is composed of a set of secondary folds, which are overturned in the same direction as the primary fold. The two sets of axial planes of the secondary folds on the opposite sides of the trough of the major fold converge upward and diverge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped.

ABNORMAL COMPOSITE FOLDS.

The upright abnormal anticlinorium.—The primary fold of the upright normal anticlinorium has a vertical, or nearly vertical, axial plane, and the limbs at corresponding points have nearly

equal average dips in opposite directions. The primary fold is composed of a set of secondary folds, which at the crest are upright, and in passing in either direction transverse to the

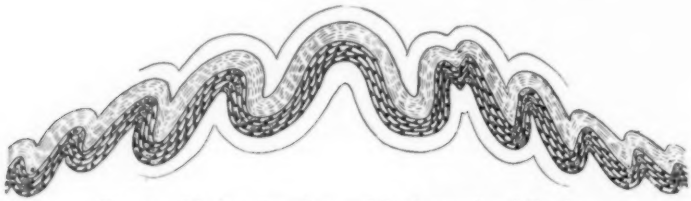

FIG. 12.—Ideal section of an upright abnormal anticlinorium.

primary axial plane the secondary folds are first inclined and then overturned. The two sets of secondary axial planes on opposite sides of the crest converge upward and diverge down-

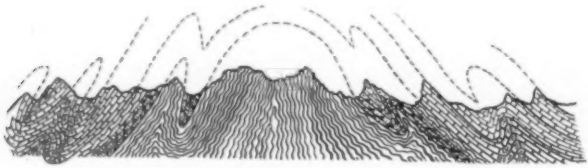

FIG. 13.—General section of roof structure in the central massif of the Alps. After Heim.

ward. The secondary folds may be ordinary, isoclinal, or fan-shaped (Figs. 12 and 13).

The inclined abnormal anticlinorium.—The primary fold of the inclined abnormal anticlinorium has an inclined axial plane, and the limbs at corresponding points have unequal average dips in opposite directions. The primary fold is composed of a set of secondary folds, all of which are inclined or overturned. The two sets of secondary axial planes on opposite sides of the crest converge upward and diverge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped.

The overturned abnormal anticlinorium.—The primary fold of the overturned abnormal anticlinorium has an inclined axial plane,

and the limbs at corresponding points have equal or unequal average dips in the same direction. The primary fold is composed of a set of secondary folds, which are overturned in the same direction as the primary fold. The two sets of secondary axial planes on opposite sides of the crest converge upward and diverge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped.

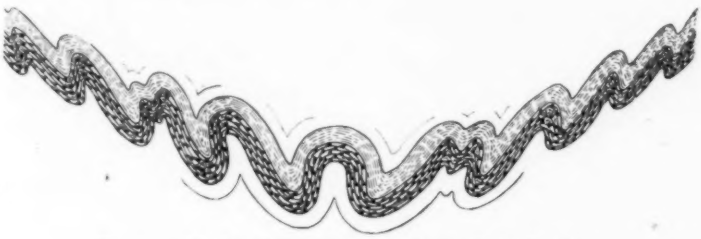

FIG. 14. — Ideal section of an upright abnormal synclinorium.

The upright abnormal synclinorium. — The primary fold of the upright abnormal synclinorium has a vertical, or nearly vertical, axial plane, and the limbs at corresponding points have nearly equal average dips in opposite directions. The primary fold is composed of a set of secondary folds, which at the trough are upright, and in passing in either direction transverse to the primary axial plane the secondary folds are first inclined and then overturned. The two sets of secondary axial planes on opposite sides of the trough diverge upward and converge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped (Fig. 14).

The inclined abnormal synclinorium. — The primary fold of the inclined abnormal syclinorium has an inclined axial plane, and the limbs at corresponding points have unequal average dips in opposite directions. The primary fold is composed of a set of secondary folds, all of which are inclined or overturned. The two sets of secondary axial planes on opposite sides of the trough diverge upward and converge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped.

The overturned abnormal synclinorium.—The primary fold of the overturned abnormal synclinorium has an inclined axial plane, and the limbs at corresponding points have equal or unequal average dips in the same direction. The primary fold is composed of a set of secondary folds, which are overturned in the same direction as the primary fold. The two sets of secondary axial planes on opposite sides of the trough diverge upward and converge downward.

OCCURRENCE AND ORIGIN OF COMPOSITE FOLDS.

Higher orders of folds.—In all of the above cases the secondary folds of the primary anticlinoria and synclinoria may themselves be anticlinoria and syclinoria. The tertiary folds of the secondary anticlinoria and synclinoria may also be anticlinoria and synclinoria, and so on to the *n*th order. The higher orders of the anticlinoria and synclinoria are microscopic. Each higher order of anticlinorium and synclinorium may be described with reference to the anticlinorium and synclinorium of the next lower order in a manner similar to the description of the primary anticlinorium and synclinorium with reference to a simple fold of the first order of magnitude.

Even in regions of gentle folding, looked at in a large way, anticlinoria and synclinoria are the rule rather than the exception. In regions of moderately close folding the secondary anticlinoria and synclinoria, as a rule, are themselves anticlinoria and synclinoria. However, it is in such regions as the Alps, Canada, eastern United States, and Lake Superior that occur the complex anticlinoria and synclinoria composed of folds of different orders up to the *n*th order.

The primary anticlinoria and synclinoria are usually upright or slightly inclined. The higher orders of anticlinoria and synclinoria are usually inclined or overturned. The very large synclinoria and anticlinoria on the flanks of the massifs of the Alps, in the Green Mountains of Massachusetts, the southern Appalachians, and many other mountain ranges, many of them miles in length, are to be considered as secondary folds composing a

part of the primary anticlinoria, each of which includes a central massif and both its flanks. By an examination of the published transverse sections of the Alps and Green Mountains (see Fig. 19) it will be seen that they are usually complicated fan-shaped anticlinoria, which are composed of complex normal and sometimes abnormal anticlinoria and synclinoria. In each normal anticlinorium, of whatever order, the axial planes of the folds of the next higher order diverge upward and converge downward, while in each normal synclinorium the axial plane of the folds of the next higher order converge upward and diverge downward. In the abnormal anticlinoria and synclinoria the reverse is the case.

Origin of normal folds. — As has been stated, the forces which act upon rocks when being folded are assumed to be tangential thrust and gravity. In the smaller folds, thrust may be thought to be the dominant force, the other being the modifying force of varying strength. In the great folds of the earth, gravity may be thought to be the dominant force, which by differential depression relatively raises a great anticline or depresses a great syncline, while thrust may play a subordinate part, being the dominant force in the production of folds of the second and higher orders. In folds of intermediate size, each of the forces may be about equally important. The relative value does not matter so far as the foregoing analysis is concerned, as in all three cases the resultant forms fall within the classes given. As long as we are so far from agreeing upon the forces which produce mountain ranges, and their manner of work, it seems best to classify the forms of folds as we find them, and to explain their origin so far as we are able. If thrust and gravity be conceived as acting uniformly upon horizontal homogeneous rocks, which are under such conditions as to bend without breaking, normal anticlinoria and synclinoria will be produced. Because of initial dips (as explained by Willis), or unequal superincumbent weight, or other causes, or one or more of these together, rocks when subjected to thrust and gravity rise into an anticline here or fall into a syncline there. But there is unequal weight upon

the different parts of each anticline and syncline. The large basins of deposition are not simple, but undulating. These secondary undulations are composed of smaller ones, and so on until ripple-marks are reached, and even these are composite. Each curve is composed of rhythmical curves of a higher order; hence the arch or trough which forms is not simple, but is composed of a number of minor folds, and these again of those of a higher order.

At first the anticlinorium is upright, or nearly so, as are also the folds of a higher order which compose it, but the secondary folds on the flanks of the primary fold point slightly outward, although the accommodations between the beds compensate in part for this (Figs. 15 and 16). As the limbs of the anticlinorium become steeper the secondary folds on the limbs are thrown farther and farther away from the axis of the primary arch (Fig. 7). If unaffected by other forces, when the primary fold becomes steep the secondary folds on the limbs become much inclined or overturned. When the limbs of the primary folds become vertical, the secondary folds on the limbs become lying or recumbent. In all cases, therefore, the axial planes of the secondary folds diverge upward and converge downward. The force of gravity may enter to further modify the forms of the folds. When a fold is inclined, its own weight and that of the superincumbent beds tend to push it over still farther. The effectiveness of gravity in this work is doubtless in part due in many cases to partial escape from thrust because of the relative rise above the deep-seated beds largely transmitting the horizontal force. (See p. 318). The farther the secondary folds are inclined, either by the increased steepness of the primary fold or by the effects of superincumbent weight, the more effective is gravity in pressing them down still farther (Fig. 8). When the weight of the superincumbent material is great, these folds may be pressed into a recumbent position, even where the primary anticlinorium is a gentle fold. Thus are explained the composite normal anticlinoria of the Alps.

At first a synclinorium is upright, or nearly so, as are also the

folds of the next order which compose it, but the secondary folds on the primary fold point slightly inward, although the accommodations between the beds compensate in part for this (Figs. 15 and 16; see p. 331). As the limbs of the synclinorium become steeper the secondary folds on the limbs are thrown farther and farther toward the axis of the primary trough. If unaffected by other forces, when the primary fold becomes steep the secondary folds on the limbs become much inclined or overturned. When the limbs of the primary fold become vertical, the secondary folds on the limbs become lying or recumbent. In all cases, therefore, the axial planes of the secondary folds converge upward and diverge downward. But the force of gravity enters to further modify the form of the folds. When a fold is inclined, its own weight and that of the superincumbent beds tend to push it over still farther. The effectiveness of gravity in this work is doubtless in part due in many cases to partial escape from thrust because of the relative rise above the deep-seated beds largely transmitting the horizontal force. (See p. 318.) The farther the secondary folds are inclined, either by the increased steepness of the primary fold or by the effects of superincumbent weight, the more effective is gravity in pressing them down still farther (Fig. 11). When the weight of the superincumbent material is great, these folds may be pressed into a recumbent position, even when the primary synclinorium is a gentle fold. In the synclinoria on the flanks of the Alps, which are secondary to the great primary anticlinorium, the crests of the recumbent secondary folds sometimes nearly meet, thus almost closing the synclinorium.

The question may be raised as to the effectiveness of superincumbent weight in pressing down inclined folds. It has been explained[1] that zones of folding of rock masses are necessarily zones of readjustment or of partial rock flowage. The flowage is from the places of great compression to the places of less compression. Where the weight of the superincumbent strata is so great as to equal or surpass the strength of the rocks folded, it appears

[1] This JOURNAL, Vol. IV., pp. 209–212.

clear that gravity must be an important force, which may greatly modify the forms of folds. The particular form of fold in a given case is of course the resultant of all the forces which work upon the rock stratum composing it.

So far as I am aware, Dana,[1] in 1847, was the first geologist to call attention to the principle that folds may be modified by the force of gravity. As is well known, this idea has been recently emphasized by Reyer.

Origin of abnormal folds. — In the abnormal anticlinorium and synclinorium new factors enter to modify the result. The first is readjustment between the beds. Fig. 15 represents a draw-

FIG. 15. — Representation of simple symmetrical folds, with their axial planes drawn on the ends of a bunch of smooth paper three-fourths of an inch thick.

ing of a number of upright folds made upon the ends of a bunch of smooth sheets of paper three-fourths of an inch thick. The sheets may be taken to represent thin beds in a nearly homogeneous rock. Fig. 16 represents this same drawing as it was distorted when the bunch of paper was folded into anticlines and synclines between blocks of wood. It will be seen that, consequent upon the readjustment of the sheets over one another, rendered necessary by the folding, the secondary folds at the crests and the troughs remain upright, although compressed if a secondary anticline or syncline corresponds with a primary fold of the same kind, and dilated if a secondary anticline or syncline corresponds with a fold of the opposite kind, and vice versa. If the secondary folds were slight, the opening might go so far as to obliterate them and the only remaining effect be to flatten the primary anticlines or synclines. The secondary folds on the limbs of the primary folds are distorted. The readjustment therefore mainly affected the forms of the fold upon the limbs. Taking as their axial planes the radial planes of the primary

[1] Geological results of the earth's contraction in consequence of cooling, by JAMES D. DANA, Am. Jour. Sci., 2d ser., Vol. III, p. 185, 1847.

folds, the secondary folds on the limbs are seen to be inclined. In reference to a primary anticline, the axial planes of opposite folds converge downward; in reference to a primary syncline, the axial planes of opposite folds diverge downward, but both less than they would were it not for readjustment. The above experiment does not exactly represent the conditions in nature, for the accommodations between the beds, instead of occurring parallel to the primary folds, would take place parallel to the secondary folds. However, an examination of the distortion of the axial planes of Fig. 15, shown in Fig. 16, shows beyond question that

FIG. 16. — The same, as it was distorted when folded into anticlines and synclines.

when a set of beds is folded which are free to adjust themselves parallel to bedding, the movement of the material in the upper half of the beds is relatively away from a syncline toward an anticline, and the movement of the lower half is away from an anticline toward a syncline; or, stated more generally, the differential movement between any two adjacent beds on the legs of folds is relatively up in the higher bed and relatively down in the lower bed. It cannot be doubted that the sum total of the readjustments between the beds, although they follow the crenulations instead of being exactly parallel to the primary fold, would give the same effect. Therefore there is a tendency in anticlinoria and synclinoria, due to normal differential movement, for secondary folds to become inclined, taking the radial planes of the primary folds as axial planes of the secondary folds. However, when the readjustment is uniformly distributed this tendency does not so far affect the secondary folds but that they fall within the class of normal composite folds. But if the major readjustment of a great set of formations were largely concentrated along a

single one in it, anticlinoria might have the axial planes of the secondary folds converge upward and diverge downward, and synclinoria might have the axial planes of the secondary folds diverge upward and converge downward, and thus both become abnormal. This readjustment along the beds, as explained in my paper in the following number, may in many cases be considered as movements along shearing planes.

The second new factor in the production of abnormal folds is the great strength of the older rocks. For a given region, upon the average, rocks become stronger with increase of age. There are innumerable exceptions to this if too small portions of geological time be compared, as period with period, but comparing era with era such exceptions are rare or altogether absent. The Archean rocks are usually stronger than the Proterozoic, the Proterozoic rocks are stronger than the Palæozoic, the Palæozoic rocks are stronger than the Mesozoic, and the Mesozoic rocks are stronger than the Cenozoic. This in the sedimentary strata is due to the indurating effects of various geological forces. In mountain ranges, where complex anticlinoria and synclinoria mostly occur, a great thickness of strata is concerned in the major folds, in most cases more than the deposits of an era; so that upon the whole in great mountain masses the lower groups of rocks are stronger.

The third cause of the production of abnormal folds may be decreasing lateral stress with increasing depth. That such variation in stress is a general fact must be true if the theory of the level of no lateral stress at a moderate depth be correct. It has been pointed out (pages 210–212) that folds must die out with increasing depth unless there is great rearrangement of material. If it be supposed that the opposing stresses upon opposite sides of an anticline or syncline decrease with depth, there will certainly be more decided folding of the higher strata than of the lower. This implies upward differential movement of a higher stratum as compared with a lower beyond that required for normal readjustment. (See p. 331). Consequent upon this there will be a tendency for the axial planes of secondary folds on

anticlinoria to diverge downward, and for those on synclinoria to converge downward.

Another factor in the production of abnormal composite folds is the position of the fold in the group of rocks folded. The farther the rocks are below the surface the greater is the weight of superincumbent strata and the more forceful is gravity in pressing to a recumbent position the inclined secondary and tertiary folds of great anticlinoria or synclinoria. As has been seen, the inferior strength in the upper strata and the lessened weight to which the upper strata are subjected are not usually sufficient to prevent thrust and gravity from acting in the ordinary way and producing normal anticlinoria and synclinoria.

In both the abnormal anticlinorium and synclinorium the application of the above causes to their formation are identical. To make this clear the following figures are drawn: Figs. 17 and 18 each represent four strata, the lower two of which are strong and the upper two of which are weak, each figure comprising one-fourth of a wave and the other being its complement. In each case the figure ends on one side at the crest and on the other at the trough of the flexure. There is nothing to indicate whether either is a part of an anticline or a syncline. Each, in fact, may be half of either, for, put end to end in one way, they form an anticline; in the other, a syncline. In both cases the lower rocks constitute a relatively rigid inclined plane. If the superincumbent weight is not too great when thrust occurs, in certain cases the softer rocks above may yield to the forces to a greater degree than do the rigid rocks below, and thus tend to flow over them, and in case the upper strata be much weaker than the lower, or there be a plane of weakness, the differential flow will be largely concentrated along the contact or weak zone, and normal secondary folds which have before developed may be inclined in an opposite direction from their first position, so as to become abnormal. This case is represented by the middle parts of Figs. 17 and 18. Put together end to end in one way the prominent secondary folds form an abnormal anticlinorium; in the other, an abnormal synclinorium. It will be noted that

in passing away from the central zone of plications either into the more rigid rocks below or into the softer rocks above the secondary folds become normal. Considering the two figures put together to represent a great flexed mountain mass, and supposing erosion to truncate the layers to the horizontal line drawn, there would be exposed normal folds at the center of the anticline, abnormal ones upon the flanks, and normal ones at the outer parts of the mountain mass. In nature we can never hope to see such a great composite fold in all its parts. It is only in the great mountain masses where such folds have been dissected that we can get at their character. In such cases the older and newer strata would be expected to show the normal forms, the intermediate strata the abnormal forms. The change from normal to abnormal and to normal again is apparently that which actually occurs in the Alps from the St. Gothard massif south to the great valley of Switzerland.

The manner in which the more rigid rocks escape large plications while the weaker beds are strongly plicated, producing abnormal folds, is well shown by Fig. 13, given by Heim as a general section showing roof structure in folded sediments and a central massif. In the production of actual abnormal anticlinoria and synclinoria it is probable that accommodations as illustrated by Figs. 15 and 16 are largely concentrated as illustrated by Figs. 17 and 18. Therefore the production of abnormal anticlinoria and synclinoria may be summarized as follows:

When two groups of rocks of unequal strength, not deeply buried, are folded into an anticline, on account of the natural readjustment of strata, of the relative weakness of the upper, newer group of rocks, and probably of decreasing differential stress with increasing depth, there may be differential flow on either side toward the axis of anticlinorium over the lower, older rocks, thus producing secondary folds, the axial planes of which converge upward and diverge downward. Had the rocks been of equal strength, or had the weight of the superincumbent strata been sufficient to more than overbalance the difference in strength and difference in stress tending to produce folds point-

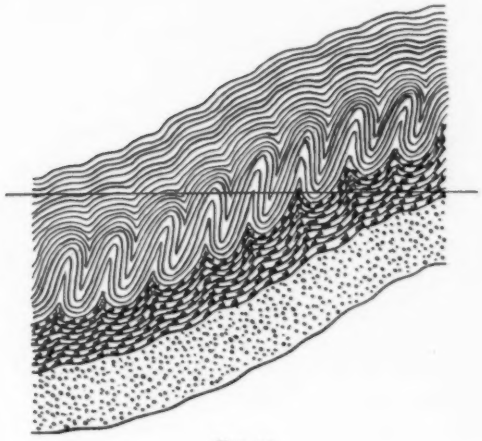

FIG. 17.

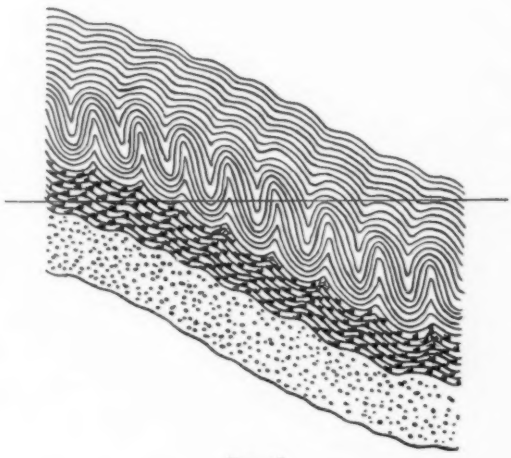

FIG. 18.

FIGS. 17 and 18. — Observe halves of composite folds, showing development of abnormal folds and their relations to normal folds.

ing crestward, normal secondary folds pointing outward would have developed.

When two groups of rocks of unequal strength, not deeply buried, are folded into a syncline, on account of the natural readjustment of the strata, of the relative weakness of the upper, newer group of rocks, and probably of decreasing differential stress with increasing depth, there may be differential flow of the rock material on either side away from the axis of the synclinorium over the lower, older rocks, thus producing secondary folds, the axial planes of which diverge upward and converge downward. Had the rocks been of equal strength, or had the weight of the superincumbent strata been sufficient to more than overbalance the difference in strength and difference in stress tending to produce folds pointing troughward, normal secondary folds pointing inward would have been developed.

Crystalline or core rocks are apt to be more massive and stronger than the little altered sedimentary beds, and therefore the core rocks usually act to a certain degree as a unit when subjected to thrust. Secondary abnormal folds are frequently found at the contact of massifs and the overlying rocks. However, even in these cases the folds will be normal if only the thickness of the superincumbent beds be sufficient. At a considerable depth the different strength of rocks is not so potent as gravity in giving form to folds. From the above it does not follow that the massifs or portions of them do not take part in the folding. That they do in many regions is certain, as is shown by infolding of core rocks with sedimentary beds, even when the massifs were originally granite. Also that massifs may take part in the folding is shown by the minor and major folds of their parts, which in form are like those of the associated sedimentary rocks.

It is recognized, however, as explained upon a subsequent page, that massifs, because of their homogeneous character, because they are underlain by no definite stratum of rock of a different character, and because they are often so deeply buried, may act in quite a different fashion, under the forces of folding, from ordinary sedimentary layers.

Causes modifying the forms of folds.—The foregoing discussion has been carried on as though the active forces of deformation are equal in opposite directions, and are acting in the same zone from opposite sides of the deformed area. If this were the case if the strata affected were of the same thickness and strength, if the initial dips were equal in opposite directions, and if the other conditions were the same, a strictly symmetrical arrangement of folds might be expected. But these conditions are never true. In the great majority of cases the facts do not depart so far from them but that the folds which form fall within some of the classes given. However, there are a number of ways in which the forms of folds may be modified.

Major faulting may interfere with their forms. Minor slip-faulting, as explained upon a subsequent page, may dominate an entire area. Igneous intrusions may disturb beds in many ways. Where these modifying causes are found the structure is the resultant of all the movements.

Finally it often happens that there is a tendency for the axial planes upon one side of an anticlinorium or synclinorium to be steeper than those upon the other. In some cases the axial planes of all the folds throughout a mountain mass may be inclined in the same direction. Such folds may be called *monoclinal*. In such cases the force, and consequently the movement of the strata, have usually been supposed to be more largely from one direction than from the other, and the axial planes of the folds have usually been regarded as dipping toward the force.

Various explanations have been offered as to how the forces act upon the strata in the actual production of monoclinal folds. Of these explanations, that offered by Rogers appears most probable for piles of strata of like rigidity. Believing as he did that the folds of the Appalachians were analogous to the waves of the sea, he naturally concluded that the tendency to a southeastward inclination of the folds of the Appalachians was due to the fact that the center of disturbance and resultant waves came from the southeast. While not following him in his explanation of folds as great waves suddenly formed, the idea seems reason-

able that the "forward thrust operating upon the flexures . . . would steepen the advanced side . . . precisely as the wind acting upon the billows of the ocean forces forward their crests and imparts a steeper slope to their leeward sides."[1] For we now regard folded rocks as plastic when bent. The compressive stresses do not extend to an indefinite depth, but are limited by the level of no lateral stress. They therefore affect the outer skin of the earth, just as does the wind the superficial water of the ocean. As a result there is a differential movement due to friction, the amount of movement upon the average gradually decreasing below the zone of maximum movement. Of course the sums of the forces, including friction are always equal in opposite directions, but they constitute a vertical couple, *i. e.*, "Two equal and parallel forces opposed in direction, but not in the same straight line." As a result there is differential movement of the material of the upper zone as compared with the lower, the former being thrust over the latter.

Other things being equal, where the differential thrust is greatest the first inclined fold is formed. The folding piles up the strata. After a time the increased thickness of material is sufficient to present a larger total resistance to deformation than the thinner strata in advance. This stress will then be transmitted forward. On account of the greater stress per unit of area, a second fold, similar to the first, will then be formed, but this results in again thickening the mass subject to the force couple, and again the stress is transmitted forward. A new inclined fold is then produced, and so on.

It is not necessary that one inclined fold shall be completely formed before others begin to develop. Indeed, this is not to be expected, for as soon as any thickening of the deformed mass occurs the conditions are favorable for the forward transmission of the effective stress. Thus many folds may be in process of formation at the same time and so far as I can understand,

[1] On the Physical Structure of the Appalachian Chain, as exemplifying the laws which have regulated the elevation of great mountain chains generally, by W. B. ROGERT, Proc. Assn. Am. Geol. and Nat. for 1840–2, p. 512, Boston, 1843.

there is no reason why differential movement should not be initiated at the same time wherever the conditions are favorable throughout the area in which monoclinal folds are observed.

It is to be noted that, under the assumption that the effective stress moves the upper strata over the lower, the vertical component of deformation is upward rather than downward. In other words, it is in the direction of easiest relief, and this is the kind of deformation one would expect, and which doubtless prevails in the majority of movements of the first order, in which thrust is the dominant force, for it has been seen (p. 332) that, upon the average, rocks are stronger with increasing age, and hence, there is greater resistance centerward than surfaceward, Folds thus produced by upper differential movement may be called "overthrust folds." The axial planes dip toward the effective stress, hence *overthrust folds are those in which the axial planes dip toward the force producing them.*

While the development of overthrust folds is the general law, it may not infrequently happen that under favorable conditions beds or formations may be thrust forward and downward. Folds thus produced by downward differential movement may be called "underthrust folds." The axial planes dip away from the effective stress, hence, *underthrust folds are those in which the axial planes dip away from the force producing them.*

In the rocks of a system or group strong formations may be above weak formations. In this case the strong formations are able to transmit the forces to a greater degree than the beds above or below. As pointed out by Willis, a forward downward movement may be directed by initial dip, and thus underthrust folds be produced. In a second case the strata pile up as a result of the folding. The relatively raised masses may then to a certain extent escape active thrust. (See Fig. 6 and p. 318.) The strata largely transmitting the thrust in front of the folded material may under these conditions be pushed under the higher mass. Underthrust folds are most likely to occur if the two conditions above given favorable to their formation are combined, *i. e.*, weak formations below and piling up of strata.

In considering the force couples in normal and abnormal composite folds, each composite limb between trough and crest must be separately analyzed. (See Figs. 17 and 18.) In normal anticlinoria and synclinoria gravity has been seen to be the efficient force which causes differential movement (pp. 328–330). Gravity works down the slope. The axial planes of the secondary folds dip toward the force (see Figs. 8 and 11), and the secondary crenulations are therefore overthrust folds. In abnormal composite folds it has been explained (pp. 330–333) that the differential movement may be caused by (1) normal readjustment, (2) increased strength of the rocks with increasing depth, and (3) the possible decreasing lateral stress with increasing depth. The first of these is eliminated for the present purpose. The second and third, either singly or together, must be sufficient to overcome gravity and to give a resultant force directed up the slope, in order that abnormal folds may be formed. (See Figs. 12 and 14.) The axial planes therefore dip toward the force, just as in normal composite folds, and the secondary crenulations are therefore overthrust folds.

By the above it is not meant to imply that underthrust folds may not be produced in either normal or abnormal composite folds, for if the conditions given on previous pages favorable for underthrust folds locally occur, crenulations of this type may be formed.

The formation of monoclinical folds is sometimes well illustrated by the crenulations of a lava bed in which there was differential flow down a slope, the upper layers moving faster than the lower. Monoclinal folds thus formed are usually not large. The directing force was gravity, and the axial planes dip toward the force. The crenulations are therefore overthrust folds. Since ordinary folds, which form without fracture, develop in the deep seated zone of flowage, the analogy with contorted lava currents is believed to be closer than might be at first thought, although it is not meant to imply by this that the folded rocks are really fluid, but merely that a plastic solid under sufficient differential stress is deformed in the same fashion as is a viscous liquid.

It has been pointed out (p. 331) that in ordinary folds the movement is relatively up for a higher stratum as compared with the one next below it. In the case of overturned monoclinal folds (Figs. 3 and 4) the later differential movements of the strata on the longer limbs of the folds may continue quite to and past the crests of the anticline, so that the differential movement on the shorter limbs of the folds is relatively down for the superior stratum geologically as compared with the inferior. However, in this case, when the folds are overturned, with reference to the horizon on the inverted limb, the movement of the higher stratum would still be upward, as compared with the one below it. This may be called *reverse differential movement*, and it may continue so as to more than compensate for the normal differential movement, but the resultant differential movement would be less on the steeply inclined or overturned limbs of the folds than on the longer, flatter limbs, since on the latter the motion is continuously in the same direction.

FIG. 19.

In the case of monoclinal folds it will be shown in my paper in the following number of this JOURNAL that the shearing is greater on the longer, more gently inclined limbs than on the shorter, more steeply inclined limbs. As a result of this the former are not so thick as the latter and are usually more metamorphosed.

Examples of composite folds.—In the United States, Mount Greylock, the Taconic range, and the valley between constitute a great normal anticlinorium. The same is true of Mount Washington, in Massachusetts (Fig. 19). A cross-section of the central part of the Marquette district furnishes an example of a great abnormal

synclinorium. The abnormal character is due to the very great difference in strength between the Archean granite and the Algonkian Lower Marquette formations. At the east end of the Marquette district, where the Archean rocks are relatively weak schists, the synclinorium is normal.

Limit of term fold.—By the above analysis and examples it is not meant to imply that, where sediments were deposited off a land area and the land and sea areas were afterwards compressed, producing undulations in the sedimentary rocks, and often in those also of the original land areas, the terms anticlinorium and synclinorium are properly applicable to the primary flexures. Following Dana, as indicated on a previous page, such flexures are more properly described as geanticlines and geosynclines. In such cases, however, there is a differential uprising or subsidence, in many cases producing a composite flexure. It is believed that the principles applied to primary folds of true anticlinoria and synclinoria apply to the secondary folds in question. just as though they together constituted a part of an ordinary fold. When gravity controls their form they are normal. When the difference of strength of the rocks controls their form they are abnormal.

As a matter of fact, it is often difficult to determine in a given mountain range whether the so-called core rocks were deeply buried under a great thickness of sediments, being, perhaps, in or near the center of the trough of deposition, or whether they were, and continued to be, land areas. It is thought that it is one of the advantages of the treatment given that it is not necessary to decide this question before working out the structure of the district. In either case the types of flexures of the second and higher orders formed on the primary flexures and the laws controlling them are the same.

Movements continuous or discontinuous.—Composite folds may be the result of forces acting continuously or discontinuously. The different secondary folds may develop at different times. The higher orders of folds may begin to form only at a late stage of development. Usually it is impossible to determine whether

thrust was continuous or discontinuous. However, if the intervals between the successive movements were sufficiently long and the conditions were such that crevices could be formed and these were filled with secondary minerals, or if cementation or metasomatic changes produced new minerals, or if within the strata igneous rocks were intruded, the later dynamic effects upon such new material may enable us to determine the fact of different movements.

In the Hiwassee section of the Ocoee series, in the southern Appalachians, in the more closely folded part of the section, quartz veins have formed in a first set of crevices. The rocks have been subsequently folded so as to closely plicate these veins, and after this folding a second set of unfolded quartz veins has formed. In other parts of the section only unfolded quartz veins are seen. This shows that certain parts of the area were affected by two periods of folding separated by a long interval.

COMPLEX FOLDS.

ORIGIN OF COMPLEX FOLDS.

Thus far folds have been considered in two dimensions only and have been treated as though they were continuous and had continuous axial lines, each one being a great circle of the earth. Such is not the case in nature. In a given fold, in passing from place to place, the direction and inclination of the crest-line are different, and it is rarely, if ever, a part of a great circle. Its deviation from the horizontal at any point gives the inclination of the fold at that point. This inclination, measured in degrees, is known as the pitch. Also when a fold is followed longitudinally, or in the third dimension, it changes continuously in size and character. A fold of the greatest magnitude may be followed along the third dimension until it dies out. The most closely compressed and intricately composite fold may be followed in the third dimension until it becomes a gentle composite fold or even disappears. When a primary fold is traced in the third dimension it may be found to grade into a secondary fold. At the same time a secondary fold on the flank of a primary fold

may itself become the primary fold. On any fold a new secondary fold may appear, and when followed longitudinally may become more and more important until it is the dominant fold. In short, in a composite set of folds each fold of any order is constantly changing in character and importance.

In a given fold all of the changes may occur, and thrust may have acted only in a single direction. The initial dip of the beds may have been different. The thickness and strength of the beds may have varied from place to place. Thrust may not have been equal along the border of the entire area affected. It may not have continued to act as long in one place as in another. Therefore there is great variation in the character and size of folds at their different cross-sections. Gravity is always toward the center of the earth; therefore variation in its direction does not enter as a modifying force.

Further, in the foldings of rocks thrust is rarely, if ever, in a single direction. Usually, when complex thrusts are decomposed in two directions at right angles to each other, one is more powerful than the other. The greater force may be called the major thrust, and the lesser force may be called the minor thrust.

Major and minor thrusts may unite in a resultant effect and produce a set of folds in a position intermediate between those that the two sets would have if each thrust had been alone. It is possible and even probable in many cases, that after a thrust in one direction has produced a set of folds, a new thrust at an angle less than a right angle to the first may be decomposed into two forces and result in further folding the first set of folds, and perhaps in the production of transverse folds, rather than in producing a new diagonal set; for when rocks are once bent in a given place they bend farther much easier at this place in the same direction than at a new place in a new direction. This principle is well illustrated by the folds of the Jurassic limestone of the Jura Mountains (Fig. 6). The transverse component of the lateral thrust may be too weak to produce any considerable effect. In such cases it would be difficult or impossible to discriminate a set of folds thus formed by two diverse thrusts from a set

formed by simultaneous or successive thrusts in a uniform direction. However, if there be sufficiently strong thrusts in two or more diagonal directions, or two thrusts at right angles, two sets of folds are produced which intersect each other. Such a district may be described as one of complex folding. The more important set of folds, corresponding to the major thrust, may be called the major or longitudinal folds, and the cross folds, corresponding to the minor thrust may be called the minor or transverse folds.

CHARACTER OF COMPLEX FOLDS.

From analysis, as well as from observation, it is found that cross folds are usually nearly at right angles to each other ; for as already explained, if the diverse thrusts be inclined to one another, they will be resolved into two forces, one of which forms the major folds, and the other of which produces cross folds in a direction at right angles, or nearly so, to the first set of folds.

Major and minor cross folds may be produced by continuous forces in both directions, or in each direction each force may be continuous or discontinuous. To ascertain these points the same criteria are available as in the case of thrust in a single direction (see pp. 342–343).

Longitudinal and transverse folds may each be classified into upright, inclined, or overturned. Each of these may be ordinary, isoclinal, or fan-shaped. Simple folds may unite to form composite folds. The composite folds may be normal or abnormal, and each synclinorium or anticlinorium under each class may be upright, inclined, or overturned.

As complex folds actually occur in the field, usually the compression is not close in both directions. Cases are known, however in which a set of longitudinal overturned folds have transverse folds with vertical dips, and the dips of the transverse folds in intricately folded districts are in many cases as steep as 45° or 60°.

When the major folds are close, as compared with the minor folds, the complex folds have great length as compared with the breadth and are canoe-shaped. The Appalachians in the closely

folded districts may be taken as a type of such complex folding. That initial dip is not sufficient to explain the pitch of the folds in this region is shown by the following facts: A stratum or set of strata may rise at one end of a synclinal canoe. Beyond this for a distance the strata are removed by erosion, but farther on appear again plunging downward at the end of another canoe. Corresponding phenomena are observed in reference to anticlines.

In proportion as the major and minor thrusts approach each other in power, the canoes become shorter and broader. Where they are nearly equal the folds are domes and basins. Usually these domes and basins are associated with canoes, which may be in one or two directions in the same region. Where the two sets of cross folds are about equally conspicuous the strikes and dips of the rocks vary constantly, their directions depending upon what part of the complex folds is under observation.

Where the complex folds are also composite the canoes, domes, and basins are fluted or crenulated, being composed of secondary canoes, domes, and basins. Similarly, these may be composed of canoes, domes, and basins of the third order, and so on.

OBSERVATIONS IN COMPLEXLY FOLDED DISTRICTS.

From the relations of cross folds, as above explained, it is clear that where there are complex folds the axes of one set of folds and their pitch give the direction and dip of the cross fold at that point. Therefore to fully understand a district complexly folded it is necessary to make the following observations:

(1) Determine the strike and dip of the strata at a given point. These give the resultant position of the strata as tilted by the forces of folding in both directions.

(2) Determine the direction and pitch of the axes of the major folds. The first is the direction of dip and the second is the amount of the dip of the minor or cross folds. The average strike is, therefore, determined.

(3) Determine the direction and pitch of the axes of the minor folds. The first is the direction of dip and the second the

amount of the dip of the major folds. The average strike is, therefore, also determined.

Of these three observations, the first is the only one ordinarily taken, and it is the one of the least importance in regions of close, complex folding. It is only by making the second and third observations that an adequate idea of the structure can be obtained. While the first observation may be made at any point, the second and third observations can be made accurately only along the crests of the anticlines or troughs of the synclines of the various orders of folds. Therefore, it may be necessary tc work over a considerable area in order to obtain the required data. Some practical suggestions may be offered as to the manner of determining whether or not the rocks of a district are complexly folded, and if so folded, the direction and pitch of the axes of each set of folds, and therefore the strikes and dips of the two sets of cross folds.

(1) It is advisable to look for the ends of canoes. These may be frequently found at the ends of ridges; hence especial study should be made of the folds where a topographic break appears across the ordinary ridges, either at a right or an acute angle. When once the end of a canoe is found, an observation can be made as to the direction and pitch of the axes of the fold, and thus the strike and dip of the cross fold be determined.

(2) The tops of ridges should be examined. These may be the crests of anticlines or the troughs of synclines, depending upon the topographic development of the region. Along the little cross breaks which are sure to occur, the direction and pitch of the axes of the folds may be determined. In some instances ridges are longitudinally inclined, following hard layers, and in this case there is an exceptionally fine opportunity to determine the direction and pitch of the folds.

(3) In case the two sets of cross folds are about equally conspicuous, there may be a double set of ridges and valleys cutting each other at right angles, or nearly so, and this may give a clue to the character of the folding of the district.

(4) In some cases the beds are closely plicated in one direc-

tion so as to give nearly uniform strikes. Unless closely observed it may not be noted that there are really minor rapid deviations of strike, which indicate a set of pitching folds, and a complexly folded district. The major and more important folds may be transverse to the minor plications. From what has gone before, it is plain that in such cases the important observations are not the strikes and dips of the strata of the minor folds, which vary momentarily, but the direction and pitch of the axes of the minor folds, which give the direction and amount of the dip of the major fold, and therefore the average strike.

(5) Pumpelly has called attention to the fact that discordance between strike of bedding and that of secondary structures indicates pitching folds. Where a secondary structure develops at right angles to the greatest normal pressure, or nearly so, it in many instances has a nearly uniform direction for an extensive area. In case the folds are horizontal, or the district is simply folded, this direction is the same as the strike of the rocks or the strike of the axes of the folds. Where the forces producing the folds are in two or more directions, and consequently form complex folds, the minor component, producing pitch, does not develop cleavage at right angles to itself; and the relations between the strike of bedding and that of the secondary structure vary from near parallelism on the limbs of the longitudinal folds to a direction at right angles to each other at the ends of the canoes and on the crests of the anticlines and in the troughs of the synclines. In passing from one place to the other there are found all relations between parallelism and perpendicularity. Because the area where the two are parallel, or approximately so, is greater than the area where there is an important discordance between the two, it has been customary for text-books to speak of the strike of bedding and the strike of cleavage as usually parallel. This, as has been seen, is wholly true only where the folds are horizontal, and the statement becomes more and more a partial truth as the pitch of the folds increases in amount — that is, as the less conspicuous folds become more important. Hence it is that where a secondary structure exists the relations which

obtain between its strike and that of bedding should be ascertained, and if discrepancies are found this indicates a complexly folded district.

(6) Pumpelly also formulated the principle that "The degree and direction of the pitch of a fold are indicated by those of the axes of the minor plications on its sides." This statement must be understood to apply to the direction and pitch of the primary fold at the point where the secondary fold is observed. This principle is a direct corollary from the relations of cross folds as given on a previous page, and it is of the greatest service in determining the structures of very complexly folded districts, because in them minor plications are so numerous. They may be seen in their entirety, and may therefore give the required determination of the character of the cross folds. The principle is, however, only approximately true. It would be wholly true if the secondary folds upon the flanks of the primary fold were exactly of the same character as the latter. But since the forces locally vary in direction and amount, and the rocks vary in rigidity, the direction and pitch of a secondary fold may vary somewhat from those of a primary fold. Usually this deviation is so small that the principle is invaluable in field work in regions of complex folding, and gives data of sufficient accuracy for ordinary purposes.

It is evident that in the application of all the above criteria we must consider bedding and not secondary structure. The criteria upon which this discrimination is made will be considered in a later paper.

Very often in regions of complex folding observers note only the most conspicuous folds in a single direction. The fact that folds are composite may be overlooked, and that they are complex is even less likely to be seen. The difficulty is further increased because of faults and secondary structures, such as slatiness, schistosity, and banding, which may be mistaken for bedding. The development of these structures and their relations to folds and bedding will be considered in following papers.

In ordinary districts where there are cross folds the more

conspicuous set is generally chosen as giving the direction of folds, while the less conspicuous set in the other direction is considered as giving the pitch of the folds. It does not follow that the folds giving the pitch, in the magnitudes of their vertical components, are less important than the more conspicuous longitudinal folds, for the lowness of the dips of the transverse folds may be more than compensated by their greater lengths, and the cross folds may be of the first order of magnitude in a district. Usually it is possible to work out the structure of such a district without particular attention being directed to transverse folds. They are so gentle that the changes of strike and dip are not rapid, and a satisfactory map may be made without recognition of the existence of cross folds. It is suspected that the largest folds of a district have often escaped the attention of the geologists who did the mapping.

The more complex the folding of a district the more necessary it is in determining its structure to consider the character of both sets of folds, and for very complex districts this is imperative.

By means of maps and sections it is difficult to represent the structure of a very complexly folded district, and even a dissected model does not represent it completely, as it is impossible to show in true porportion the different orders of folds, and especially those of the higher orders. It is plain that cross-sections in a single direction at long intervals fail to give any adequate idea of the structure of such a district, although these combined with geologic and topographic maps may do so. In reports the structure can best be represented by combining the geologic and topographic maps with two sets of cross-sections made at frequent intervals and at right angles to each set of folds.

It will be noted that in the foregoing treatment of folds they are classified as they occur, no ultimate theory of their origin being offered. No conception of the causes of mountain ranges enters into the analysis. It is true that an explanation is attempted of the difference between normal and abnormal composite folds. The fact that this explanation apparently accords

with the forms and distribution of folds in all of the many different districts to which it has been applied, and at the same time accords with the principles of mechanics, appears to me to give to it a considerable degree of probability. Even if the explanation be not accepted, the forms of folds and the principles applicable to their study remain the same. Thus we have a classification of folds and an outline of methods for their study which will assist in determining the structure of the complexly folded districts and in preparing areal maps of them.

CHANGES ACCOMPANYING FOLDING.

Contemporaneous with rock folding, and in a large measure dependent upon it, other changes occur in rocks. As has been seen, crevicing and brecciation largely depend upon the same forces as does folding. During the process of folding old minerals are transformed into new ones. New mineral material enters from the outside. The minerals are rearranged and mechanically modified. Secondary structures, such as cleavage fissility, joints, and faults may develop. In short, during the folding process the rocks are to a greater or less degree metamorphosed.

RELATIONS OF FOLDS AND UNCONFORMITY.

The folding of a set of inferior formations in a more compli cated manner than that of another set of superior formations may indicate a structural break between the two, and consequently that the two sets of formations belong to different series. In order that this criterion may be applied, it must be conclusively shown that the supposed upper formations are really above the others. It must not be assumed that a formation at one side of an axis of plication is in a superior position because less folded, for in many regions close folds die out within a comparatively short distance in a direction transverse to them. This is the case along the Green Mountains, where the closely folded Lower Palæozoic rocks pass quickly, to the westward, to unfolded or very gently folded ones. The change here takes place so rapidly that it has been supposed by many geologists that the more closely

folded rocks are really the older and belong to a series prior to their unfolded westward continuation. The failure to appreciate the above principle has been to a large degree the cause of the Taconic controversy.

It is believed that the cause of the frequent sudden change from closely folded to very gently folded rocks across the strike of the folds is due to the principle explained on pages 317–318. This is: Strata when once bent at a certain place continue to bend at this place rather than to form a new fold. This bending continues until, as a result of the folding, the strata are greatly thickened and the inclinations become steep, so that resistance to further folding at this place is greatly increased. The force is then transmitted forward and a new area is affected by folding, but as soon as the strata are here bent they continue to bend easily until they are closely folded, so that there is the same sudden transition as before from the closely folded to the very gently folded or unfolded districts.

In the first and simplest case the lower formations have been subjected to either simple or complex folding, while the upper formations are undisturbed or very slightly disturbed. In this case the upper formations are likely to be found as inlyers upon the other, and the structural break between the two is comparatively easy to determine. Phenomena of this kind are found at many localities between the Palæozoic and pre-Palæozoic sediments, and less frequently they are found wholly within the pre-Palæozoic formations.

The second case is that in which the lower formations were folded by one or more movements before the upper series was deposited, and subsequently the two were again folded. If the second folding was of a comparatively simple character, and the earlier was rather complex, it is usually comparatively easy to separate the two series. For instance, the lower formations may have been rather closely folded by the first orogenic movement, and the two sets of formations together may have been gently folded by the second movement. The discrepancy between the two may often be detected, even when the movements were in

the same direction, as they so frequently were. But the discordance may be more easily discovered if the second movement was in a different direction from the first, so that the first folds of the lower formations become complexly folded at the second period of folding, the newer formations at the same time being simply folded.

Third, in more complicated cases the lower formations were folded one or more times before the upper series was deposited, and after the deposition of the latter the two series were again folded in a complex fashion, either by a single orogenic movement or else by successive movements. In proportion as the folding of the later formations becomes complicated the criterion of folding for separating series is more and more difficult to apply, and where the folding of the upper formations is at all intricate it is usually of little value. The criterion of folding for separating uncomformable series is to be considered in all cases in connection with other criteria.

C. R. Van Hise.

EDITORIAL.

THE preparation of thin sections of rocks, is an art, in which few have succeeded. It appears to require patience in reducing the sections at the proper rate, and delicacy of touch in finishing them. Those of us who study rocks with a microscope are aware how seldom rock sections are prepared of the desired thinness for optical investigation. Too often the section has been left unfinished, so that the more minute crystals present a confused aggregation of indeterminable parts. There is no doubt that the difference between good and bad petrographical work is due in many cases to differences in the quality of the thin sections studied. Sections thin enough to permit the feldspar and quartz to display only the lowest gray interference color, and which reveal the minutest textures in microcrystalline or glassy rocks, are essential to satisfactory work

The petrographers connected with the United States Geological Survey have been fortunate in this respect, having been furnished with exceedingly well made rock sections, prepared for the most part by Hermann Ohm and Frederick C. Ohm. The former has left with many of us the memory of a skilled and honest worker, who won our respect and friendship; while the latter has earned an equally high place in the esteem of those who look to him for the preparations by means of which they forward their special investigations. It is not too much to say that a large part of the pleasure and satisfaction which the writer has derived from his petrographical researches is due to the excellency of the thin sections made by these workers.

It is gratifying to learn that Mr. F. C. Ohm has started his son in Washington in the business of making rock sections, and that he will be able to supervise the finishing of them and can guarantee the character of the work. It is to be hoped the son will become as expert as his father, and that the undertaking will prove successful, since it will be of great benefit to students of petrography throughout the country to have the opportunity of obtaining thoroughly satisfactory rock sections. J. P. I.

Reviews.

Geological Biology, an Introduction to the Geological History of Organisms. By H. S. Williams. Henry Holt & Co., 1895.

Of late years numerous books on evolution have appeared, but perhaps none have been more practical or suggestive in their treatment of the subject than the present volume by Professor Williams. The subject matter of the book was originally presented in the form of lectures, delivered first at Cornell University and later at Yale. These lectures were intended to supplement a laboratory course in palæontology, by suggesting the most vital lines of thought in the actual interpretation of fossils considered as the records of the history of organisms. In the preparation of the matter for publication the lecture form has been dropped and the material so revised as to serve the general reader as well as the student.

It is evident that the biologist proper, who deals alone with contemporaneous organisms, must rest with a theoretical interpretation of the laws of evolution. The actual records of the history of organisms are found in the fossils preserved in the rocks and it is the purpose of the author to point out the chief facts and factors of evolution as shown from a study of the fossils.

In beginning the study of any history some system of chronology must be adopted. In the early chapters of the book the author discusses the development of the geological time-scale as now generally adopted, passing from the earliest classification of rocks based on their original order of formation, through the second stage in which the classification was based on their mineral constituents, to the present classification based on their fossil contents.

Fossils represent the hard parts of living organisms, or those parts which have attained definite and fixed form during the life of the organism. "The history of organisms, which we particularly trace in the study of fossils, is not the history of imperfect organisms struggling towards perfection, but it is the history, for each age and epoch, of the perfected adjustment of the organisms of the time to the particular

conditions of environment in which they lived. They did not die before their time, overcome by the mythical fittest who are said to survive in the struggle. They were the fittest, and died natural deaths, having provided before they gave up the struggle for their progeny to succeed them. The hard parts record the history of adults which have endured the struggle, and thus represent the royal line of succession for the geological ages."

Evolution is a fundamental law in the geological history of organisms. The "morphological differentiation (*evolution*) is as characteristic of the history of organisms in geological time as organic growth (*development*) is characteristic of the history of the individual organism in its lifetime." With the progress of time the morphological characters assumed by organisms have been gradually and incessantly changing from the beginning. This constant change or evolution is a fundamental law of organisms. Inorganic things on the contrary are unchangeable. The chemical composition and properties of things are the same as far back as we can trace them. A quartz crystal formed in Archæan time has exactly the same form with exactly the same angles as a crystal of the same substance formed today.

A certain analogy between ontogenesis and phylogenesis is commonly recognized. As each individual has a life history, so also has each species, genus, family, etc., but this fact must be emphasized, that in the individual development a *change of function* is associated with the several stages of ontogenesis; while it is difficult to imagine any corresponding change of function in the successive representatives of a common race. For this reason great caution is necessary not to force the theory of correspondence between the ontogenetic stages of functional activity and the order of differentiation of new characters expressed in the phylogenetic history of organisms. The two series of phenomena present this marked contrast, that in ontogenesis each phase of development is a repetition of phenomena which have been repeated in the same way from the beginning of organic life, while in phylogenesis each step is a step in advance of anything that has occurred before.

Evolution and adaption are both observed facts. The continuous morphological change of organisms, coördinate with the progress of time, is evolution. In this onward progress of organisms they are everywhere locally adapted to the particular environment in which they are placed. This adaptation to environment is brought about

through the action of natural selection, but this adaptation is not the evolution nor is natural selection the cause of evolution, but only one of the factors in the process of evolution. A first cause of some sort is essential to any complete theory of evolution.

"Among those today who adopt evolution as the explanation of the mode of origin of the different forms of organisms, there are two extremes of opinion with many intermediate compromises.

"All will agree in recognizing ancestry and environment as each taking some part in the evolution; but the extreme school, on the one hand, holds that *environment* is the chief factor determining the direction and extent of the modifications, which heredity tends to perpetuate, and that ancestry plays only the part of holding and preserving, in its offspring, what it gets from the agency of environment.

"The other extreme is the opinion that *ancestry* is the more efficient factor in bringing about the evolution; that in what is called *variability* there is working out, not a mere accidental reflex of environment upon the plastic organism, but a fundamental property or force of organisms, ever tending from homogeneity to heterogeneity and resulting in the specialization of functions and the differentiation of organic structure always; the line of evolution followed out by any particular race being influenced little by environment, — the adjustments being active and not passive, — the successful organisms seeking and adopting conditions favorable for their existence if out of them, dying out if the conditions favorable are not within reach, or if crowded out of them. Natural selection to this school of opinion plays rather an eliminating rôle than one of causation, and explains rather why there are gaps in the series of organisms than why the characters assumed in the modified forms are what they are. In this latter view the successive steps of modification of a race are as much controlled by the ancestry as are the successive steps of development in the growth of the individual.

"In the former view there is the replacement of the theory of immutability of species by that of the mutability of species, but the process of reproduction is still looked upon as immutable, reproducing the characters of the parents in the offspring without change; in the second view reproduction itself takes a part in evolution and normally accomplishes modification of form, either slowly or suddenly, but progressively, and evolution is an intrinsic law of organism."

Mutability of species is the central thought in the new theory of the origin of species. Darwin first clearly announced that *species are*

mutable, and as the whole science of natural history was constructed on the idea of their immutability, a complete readjustment of the science has resulted. With the revolution of thought started by Darwin's "Origin of Species," came a new conception of the nature of species. "The change was a philosophical one; no longer was the species considered to be a permanent entity with definite boundaries, but in the definition of organic species its time-relations and its geographical distribution were elements added to those of its morphology and physiology. This was a great advance. The organism came to be recognized not as a mere concrete being independent and standing by itself, constituted at the beginning what it is and remaining so during its existence, but as a very dependent part of a greater organism, nature itself, and related intimately with its surroundings or environment, to the organisms which preceded it or its ancestry, and to those which are to follow it or its descendants, as a sensitive, slowly changing reflex of all that has been and is. In the new conception there is the dim outlining of the idea (an old idea, but one which is day by day growing more distinct and of fuller comprehension) that nature itself is a greater organism in which the species is but one of the organs."

The problem of the origin of species came to be a question for scientific investigation, only when the old idea that variations were not cumulative, but were always simply variations, was superseded by the newer idea that variations are cumulative, and that reproduction is not a process of exact but of inexact repetition of characters. Variability is thus assumed to be an inherent characteristic of all organisms. The natural inference from the Darwinian explanation of the origin of species is that characters appearing first as varieties are through continuous repetition in the process of generation, gradually elevated to specific, generic, family, etc., rank. Palæontologists are inclined to doubt the fact of natural selection playing such an all-important part in the evolution of organisms. Cope has expressed the idea that evolution of generic characters has progressed in a different way, and has developed the idea of the law of acceleration and retardation which acts in association with natural selection but independent of it. There is assumed to be a special developmental growth force which is exhibited in variation itself and which becomes effective, as phylogenetic evolution, through acceleration and retardation. The Darwinian or natural selection school of evolutionists is engaged in accounting for

the acquirement of permanence of originally variable elements, while the Neo-Lamarkian school is engaged in accounting for the variability itself.

The laws of evolution as illustrated by the life-history of the brachiopoda are fully discussed by the author. The evidence obtained from this class of organisms points to the fact that the evolution of those characters which mark the differences between separate classes, orders, suborders and even families of organisms, has taken place in a relatively short period of time; taking as a measure either the rate of general progress in the differentiation of organisms, or the length of the life period of each particular genus or family. This rapid evolution is difficult to account for by any working of natural selection. Two factors are at work in the process of evolution which are designated as intrinsic and extrinsic evolution. "*Intrinsic evolution* is conceived of as normal expansion and differentiation of the organism itself from within, and is the expression, in some way, of an intrinsic tendency of the particular race of organisms. The other, *extrinsic evolution*, expresses the limitation and selection exerted upon the organism from without."

Illustrations of the laws of evolution are further drawn from other classes of organisms as the Cephalopoda and Vertebrata. From all these illustrations it is pointed out that the geological evidence does not emphasize the importance of natural selection as a factor in evolution. The following paragraphs may be quoted as setting forth the views of author.

"That which has seemed most conspicuous to the latter class of observers (students of living organisms) has been the intimate relationship existing between morphological difference and environmental conditions; palæontological facts point to the greater importance of the continuous and progressive process of differentiation and specialization of structure and function with the passage of geological time.

"The facts examined . . . . . show that evolution is rather an intrinsic law of organisms, and is to be discovered in the phenomena of variation, which appear to be constantly active, rather than in any accidental operations dependent upon the conditions of external environment.

"Evolution is seen to be a process that is primarily organic; it is expressed in the acquirement of new characters in the course of growth by living organisms; and we may as reasonably speak of evolution as

of the growth force of the individual or the force of gravitation. As the normal laws of growth of the individual are thwarted and diverted by external conditions, so undoubtedly a greater or less modification of the course of evolution has been produced by the conditions of environment.

"When we attempt to explain the course of evolution by tracing it backward from the differentiated, adjusted organisms to its ancestors, it is natural to place great importance upon the fact of the accomplished adjustment of the individual to its particular environment; but when the point of views is reversed and the organism is traced from the earlier geological periods through the ages down to the present time, the conviction becomes impressed upon the student that environmental conditions are but the medium through which the organic evolution has been determinately ploughing its way." S. W.

Canadian Fossil Insects. By S. H. SCUDDER. Contributions to Canadian Palæontology, Vol. II., Part. 1 (1895).

This publication includes three different papers by Prof. Scudder.

1. *The Tertiary Hemiptera of British Columbia.* Descriptions are given of nineteen species from three different localities—Quesnel on the Fraser, the north fork of the Similkameen River and Nine Mile Creek flowing into Whipsaw Creek, a tributary of the Similkameen. Dr. Dawson considers the two latter localities to be portions of a single ancient lake, so only two basins are concerned. The two basins afford specimens of very different character and may prove to represent different stages in the Tertiary. The age of the beds is probably as old as the Oligocene.

The great diversity of this ancient insect fauna may be judged from the fact that in nearly every case each specimen must be referred to a distinct species, and in only one case can two species be referred to the same genus. The most striking feature of the fauna is the large size of the individuals which compose it.

2. *The Coleoptera hitherto found fossil in Canada.* Fossil Coleoptera have been found in seven distinct localities at three very different horizons, viz., Post-Pliocene, thirty-two species, lower Tertiary, fourteen species, and Cretaceous, one species.

The most interesting fauna is that from the inter-glacial deposits of

Scarboro' Heights, near Toronto where twenty-nine species have been found. Not one of these can be referred to existing species. The nearest allies of several are to be sought in the Lake Superior and Hudson Bay region, but the nearest allies of the larger part of them are to be found in the general district where the deposits occur. In no single instance have any special affinities been found with any characteristically southern form, though several are most nearly allied to species found there as well as in the north. On the whole the fauna has a boreal aspect, though by no means so decidedly boreal as one would anticipate under the circumstances.

3. *Notes upon Myriapods and Arachnids found in Sigillarian stumps in the Nova Scotia coal field.* Nearly fifty years ago Sir J. W. Dawson and Sir Chas. Lyell first called attention to this unique land fauna of Carboniferous time. From time to time additional species of Articulates, Mollusks and Vertebrates have been discovered and described by Sir J. W. Dawson. The present paper by Professor Scudder gives notes and descriptions of ten species of myriapods and arachnids, some of which are new. S. W.

SUMMARY OF CURRENT PRE-CAMBRIAN NORTH AMERICAN LITERATURE.

MATTHEW[1] gives the following pre-Cambrian succession near St. John, N. B.:

A.—Laurentian.

1. *Portland group*, including Division 2, with probably parts of Division 1 in other localities than St. John.

2. *Intrusive granite* and quartz-diorite; perhaps later than the position here assigned to it.

B.—Huronian.

3. *Coldbrook group* or Div. 3, of volcanic rocks.

4. *Coastal group* or Div. 4, of volcanic and sedimentary rocks, in its upper part probably equivalent to the next group.

5. *Etcheminian or Basal Series*, of sedimentary rocks, underlying the St. John group.

6. *Kingston group* or Div. 5, of metamorphosed volcanics. Of very uncertian relations; may be post-Cambrian.

The Huronian in southern New Brunswick is in large part made up of surface volcanic rocks. The lower part or Coldbrook group is almost exclusively volcanic; the upper part or Etcheminian is clastic, while the intermediate Coastal contains both volcanic and sedimentary members. The effusive rocks include lavas, breccias, and tuffs, and with them may be placed a holocrystalline soda-granite which is probably either an intrusion or a very thick surface flow.

The Etcheminian series rests unconformably upon the Coldbrook series and unconformably below the St. John group, which is for this district placed at the base of the Cambrian. The igneous rocks comprise effusives, including quartz-porphyry, felsite-porphyry, diabase, and feldspar-porphyrites, and dike rocks, which include diorite-porphyrite, diabase, and augite porphyrite. Each of these is described in detail.

Bailey[2] gives a preliminary report upon southwestern Nova Scotia. The oldest rocks here found are those of the Cambrian system, in which there is the following succession from the base upward:

[1] The Effusive and Duke Rocks near St. John, N. B., by W. D. MATTHEW, Trans. N. Y. Acad. Sci., Vol. XIV., 1895, pp. 187–217, Plates XII.–XVII., Figs. A. B.

[2] Preliminary Report on Geological Investigations in Southwestern Nova Scotia,

1. Quartzite Division.
   (*a*) Heavily bedded blue quartzites, with slightly plumbaginous partings, alternating with numerous but much thinner beds of gray argillite. In metamorphic areas the quartzites become more micaceous, assuming the aspect of fine-grained gneisses, while the finer beds become glistening mica-schists.
   (*b*) Greenish-gray sandstones or quartzites, less massive than in (*a*) and alternating with slates which are arenaceous below, but become gradually more argillaceous above.
2. Slate Division.
   (*a*) Greenish-gray slates, becoming bluish or light gray, and passing into purple slates, or becoming clouded or zoned with shades of green, purple, blue, buff or pale yellow, often producing a conspicuous ribbanding of the beds. The occurrence of light yellowish-green seams is a characteristic feature of the purple slates.
   (*b*) Bluish-gray and blue slates, with lighter gray seams or bands, and including in places an upper zone of purple slates.
   (*c*) Black, with some blue or gray slates, often highly pyritiferous. In metamorphic regions the green slates are represented by chloritic and hornblendic schists (or locally by conglomerates with a micaceous or hornblendic base); the slaty beds by micaceous, garnetiferous, and andalusitic schists.

Above the Cambrian rocks are those belonging to the Devonian system. There are several important areas of granite, as follows: Those of South Mountains, Blue Mountains, Tusket Wedge, the Barrington area, Kelvin area, and Port Mouton area. These are intrusive within the Cambrian, and in places they clearly penetrate and alter the fossiliferous Devonian rocks.

Comments.—The rocks here referred to the Cambrian are the so-called gold-bearing slates. This great series I have regarded as probably equivalent to, and belonging in the same geological province with, slates of Newfoundland unconformably underlying the Cambrian. I have therefore doubtfully referred the Nova Scotia slates to the Algonkian. No palæontological evidence is given in this paper which decides between the Cambrian and Algonkian periods.

Bonney[1] states that the Eozoon of Côte St. Pierre is either a record of an organism, or a very peculiar and exceptional condition of a pyroxene-marble of Laurentian age, which is not a result of contact metamorphism in the ordinary sense of the term.

by L. W. BAILEY, Geol. Sur. of Can., Ann. Rep. for 1892–3 (new series), Report Q., 1895, pp. 21. With map.

[1] The Mode of Occurrence of Eozoon Canadense at Côte St. Pierre, by T. G. BONNEY, Geol. Mag., new ser., Vol. II., 1895, pp. 292–299.

Adams[1] describes a district of 3500 square miles of pre-Cambrian rocks belonging to the Grenville series immediately east of the original Laurentian area, described by Logan and Ells, and northwest of the city of Montreal. A subordinate part of the area about Trembling Mountain and another area to the west of St. Jerome are referred to the fundamental gneiss. The Grenville series occupies the major portion of the district, but about 1000 square miles is occupied by anorthosite, which occurs in one large area known as the Morin area, and ten smaller masses. The Morin anorthosite encloses detached masses of the gneiss. There are also present in the district one mass of intrusive syenite covering an area of thirty-six square miles, and a much larger one of granite in the northeast portion.

The Grenville series is composed of rocks in well-defined bands, the whole exhibiting a clear foliation, usually parallel to the banding. The series thus has a decidedly stratified appearance, similar to that presented by sedimentary rocks. The gneiss which on the west side of the area dips at an angle of 40°, toward the east become nearly flat, often quite so, and these nearly flat gneisses extend to the north and east far beyond the limits of the map. Throughout this area of flat-lying rocks, the gneisses with their interstratified limestones and quartzites are as highly crystalline as in the most highly contorted districts and have evidently undergone an extensive stretching or rolling out, resulting in the tearing apart of the less plastic bands with the flowing of the material of the more plastic bands into the spaces between the separated fragments.

Petrographically the rocks of the district are found to fall into four classes:

1. Anorthosites and granites of igneous origin. All gradations may be seen between the ordinary anorthosite and those in which the whole is granulated so as to resemble in appearance a saccharoidal marble. The whole rock thus moved under pressure like so much dough, its continuity being perfectly maintained. This is Professor Heim's "Umformung ohne Bruch," millions of little cracks taking the place of a few larger ones, and it is by this process that granites and many gneisses and other crystalline rocks when deeply buried under great pressure and probably very hot, move and accommodate themselves to stresses. This, it will be observed, is quite distinct and different from the shearing accompanied by the development of new materials, which takes place under other conditions and probably nearer the surface.

2. Augen-gneisses, leaf-gneisses, granulites, and foliated anorthosites, genetically connected with the last group, and largely, if not exclusively, of igneous origin also. The structural characteristic of this class is the cataclastic or granulated one, formed by the mechanical breaking down of the web of the rock under movements induced by great pressure, which movements produce in the rock a foliation more or less distinct, according to their intensity.

[1] A Further Contribution to our Knowledge of the Laurentian (Art. VII.), by F. D. ADAMS, Am. Journ. Sci. (3), Vol. L, 1895, pp. 58–69, with Plates I. and II.

3. A series of crystalline limestones and quartzites, together with certain gneisses usually found associated with them. In these rocks the granulated structure is very subordinate or entirely absent. They are characterized by a very extensive recrystallization with the development of new minerals. These minerals have crystallized under the influence of the pressure which granulated the gneisses of the second class, and are not in any marked manner deformed by it. These gneisses also differ from the granites and gneisses of classes 1 and 2 in chemical composition, giving analyses almost identical with those of slates. Moreover, the rocks of this class are very frequently graphitic, and analyses show that the gneisses correspond in chemical composition more closely with slates than with granites.

4. Pyroxene-gneisses, pyroxene-granulites, and allied rocks whose origin is as yet doubtful.

With regard to the Grenville series, from the presence of numerous and heavy beds of limestone and quartzite, their prevalent banded character, the widespread occurrence of graphite, and the fact that the gneisses associated with the limestones and quartzites have the composition of sands and muds and not of igneous rocks, it is concluded that it is extremely probable that this is an altered sedimentary series, which has been deeply buried, invaded by great masses of igneous rocks, and recrystallized. In places the Grenville sediments may have been mingled with the igneous rocks by actual fusion.

Smyth,[1] C. H. Jr., describes the crystalline limestones and associated rocks of the northwestern Adirondack region. The limestones, instead of being in limited patches as in the eastern part of the Adirondacks, are in extended belts many square miles in area. The limestone belt running through the townships of Rossie and Gouverneur has been traced more than twenty miles along the strike, while the average width is perhaps six miles. A narrower belt extends across Fowler into Edwards township. A third belt crosses the townships of Diana and Pitcairn, with an average width of two or three miles. In addition to these belts, numerous scattered patches have been noted in the western Adirondacks.

The limestones are highly crystalline, coarse, light gray or white rocks, containing silicates in separate crystals or segregated in lumps. Among these phlogopite, graphite, pyroxene, and tourmaline are most common. The limestone is usually so massive that it is difficult to ascertain the strike and dip with any accuracy. When observable, the strike is generally northeast and the dip northwest, though exceptions are common. Garnetiferous and micaceous gneisses and pyroxenic and hornblendic gneisses are intimately associated with the limestone. The former are in some cases distinctly inter-

[1] Crystalline Limestones and Associated Rocks of the Northwestern Adirondack Region, by C. H. SMYTH, Jr. Bull. Geol. Soc. of Am., Vol. VI., 1895, pp. 263–284.

bedded with the limestone, while many of the latter have the appearance of interbedded members, and others closely resemble somewhat modified intrusions. Wherever the hornblendic and pyroxenic gneisses appear, they show a great amount of crumpling and crushing, which goes from slight plication to elaborate contortion or to crushing into angular fragments in a paste of limestone, thus producing remarkable breccias. In all of these cases the limestone shows little or no sign of structural change, having the appearance of a plastic mass in which the contained layers could be twisted to any extent. It therefore follows that the massive and undisturbed appearance of the limestone, when free from gneissic layers, does not show that it has not been subjected to intense mechanical strain, as subsequent to this it may have recrystallized.

This limestone series has a marked resemblance to the Grenville series, but because it is difficult to establish such an equivalency, it is suggested that it be called the Oswegachie series. The areas between the belts of limestone are occupied by gneiss, whose origin and relations to the limestone series is doubtful. The limestone series can hardly be regarded as of other than sedimentary origin. In many cases these gneisses adjacent to the limestone closely resemble the interbedded garnetiferous gneisses, and doubtless should be regarded as members of the limestone series. These varieties pass gradually into more nearly massive gneisses of feldspathic aspect, and these are in a number of cases in direct contact with the limestone. A part of these gneisses at least are of igneous origin, as is shown by their contact relations, but whether this explanation is applicable to them all it is impossible to show. Intrusive in the limestone series are granite, diorite, gabbro, and diabase. Their intrusive nature is shown by all the usual phenomena characteristic of such relations.

The gabbro is most variable in its petrographical character. At one place it is in sharp contact with the granite. The relations of the gabbro to the gneiss are difficult to unravel. At Natural Bridge is found the normal gabbro, and in passing toward the red gneiss it appears to grade into it, and the two may be different facies of the same eruptive mass. The contact zones between the limestone and the intrusive gabbro are narrow and sharply defined, and this fact, combined with the great mechanical disturbances of the limestone series, justifies the conclusion that its metamorphism is largely dynamic.

Kemp[1] describes the crystalline limestones, ophicalcites and associated schists of the eastern Adirondacks. Study of the region seems to corroborate the conception of the Adirondack Mountains, as sketched by Van Hise, as a central intrusion of igneous rocks, with a fringing rim of older gneisses, schists, and limestones. A closer approximation would be to regard

[1] Crystalline Limestones, Ophicalcites and Associated Schists of the Eastern Adirondacks, by J. F. KEMP, Bull. Geol. Soc. Am., Vol. VI., 1895, pp. 241–262.

the intrusions as in several more or less parallel ranges, with remnants of the other rocks in the valleys between them and on the flanks is taken as a whole.

The limestones and the associated rocks always occur in depressions, the resistant ridges consisting of the harder gneiss or anorthosite. The former form sections as broad as 1000 feet, in which the limestone strata are, however, less than half, and the true thickness of which is difficult to determine because of the varying dips, schistosity, and possibility of faults. The white limestones are coarsely crystalline, usually graphitic, and often include silicates, from little scales to large bunches. At Keene Center, in the heart of the Adirondacks, is a white limestone and schist belt which contains magnetic iron ore, and is overlain by garnetiferous and pyroxenic schists, or pyroxenic granulite, the relations indicating that the latter is a gneissic rock interbedded with the limestone.

There is no marked break to be detected anywhere between the gneiss and the overlying limestone. Apparently the whole is a continuous series of strata, which are analogous in appearance with those of the Grenville series of Canada. It therefore does not appear certain that in the eastern Adirondack region are any rocks older than this series. The extent and persistence of the limestones and schists gives ground for believing that the series was a set of calcareous sediments and sandstones which have been metamorphosed and intruded by the anorthosites.

Kemp[1] describes the titaniferous iron ores of the Adironacks. These occur in the gabbros. The ores are regarded as segregations from the igneous magma formed during the process of cooling and crystallization.

Kemp and Marsters[2] give the field occurrence and microscopical characters of the trap dikes of the Lake Champlain region. The dikes are found to be bostonites, diabases, camptonites, fourchite, and monchiquite.

Sears[3] gives a description of each of the rocks of Essex county, Massachusetts. These comprise plutonic rocks, volcanic rocks, Archean rocks, and various metamorphosed sedimentary rocks of Palæozoic age.

Emerson[4] gives an outline of the geology of the Green Mountain region in Massachusetts. The Algonkian rocks comprise the Washington gneiss, Tyringham gneiss, East Lee gneiss, Hinsdale limestone, and Hinsdale gneiss.

[1] The Titaniferous Iron Ores of the Adirondacks, by J. F. KEMP, Abstract in Bull. Geol. Soc. Am., Vol. VII., 1895, p. 15.

[2] The Trap Dikes of the Lake Champlain Region, by J. F. KEMP and F. V. MARSTERS, Bull. 107, U. S. G. S. With map. Washington, 1893.

[3] Report on the Geology of Essex County, Massachusetts, to accompany map, by JOHN H. SEARS, Bull. Essex Inst., Vol. XXVI., 1894, pp. 118–139.

[4] Geol. Atlas of the U. S., Hawley Sheet, Preliminary Edition, by B. K. EMERSON. U. S. Geol. Sur. Washington, 1894,

This series is the equivalent of the Stamford gneiss in Hoosac Mountain. The Algonkian rocks consist of firm, coarse gneisses which contain minerals and possess structures not formed in the later rocks; thick beds of coarse and highly crystalline limestones which contain many minerals rarely found in later limestones, as chondrodite, wernerite, dark pyroxene and hornblende; and coarsely crystallized graphite; considerable beds of pyrrhotite, magnetite, and graphite also.

Because of the presence of the heavy beds of limestones, which were probably derived from shells and corals, we may assume that the whole series, except the hornblende-gneiss of East Lee, was of sedimentary origin, but we know nothing of the limits of the sea in which they were spread. These rocks are overlain by the Cambrian Becket gneiss and Cheshire quartzite. As shown by the basal conglomerate at the Dalton Club House, these rocks rest unconformably upon the Algonkian.

Emerson[1] describes the geology of Old Hampshire county in Massachusetts, which includes the present counties of Franklin, Hampshire, and Hampden. On the western border of the Green Mountain area, as it crosses Massachusetts and overlooking the Housatonic Valley, is a series of pre-Cambrian outcrops, which are the oldest rocks of the state and the substratum on which the others rest. They consist of coarse gneisses, especially characterized by blue quartz and allanite, coarse porphyritic structure and stretching; and by great beds of highly crystalline limestone, containing chondrodite, coccolite, titanite, phlogopite and wernerite.

The most important of these limestone beds are the Hoosac, the Hinsdale, and the Tyringham areas The limestone beds connected with the two latter have caused the two most important passes through the range — the Westfield Valley and the East Lee-Farmington Valley.

On the pre-Cambrian rocks rest the Becket conglomerate gneisses of Cambrian age, and above them a great series of sericite schists (the Hoosac schists, Rowe schists, Chester amphibolite and Hawley schists), which are about contemporaneous with the Stockridge limestone of the Housatonic Valley.

Dale[2] discusses the structure of the ridge between the Taconic and Green Mountain ranges in Vermont, and that of Monument Mountain in Great Barrington, Mass. He finds all the strata concerned to be Cambrian or post-Cambrian.

[1] Geology of Old Hampshire County, in Massachusetts, by B. K. EMERSON, Abstract in Bull. Geol. Soc. Am., Vol. VII., 1895, pp. 5–7.

[2] On the Structure of the Ridge between the Taconic and Green Mountain Ranges in Vermont, by T. NELSON DALE, Fourteenth Ann. Rep. U. S. G. S. (for 1892–3), Part II., 1894, pp. 525–549; and, The Structure of Monument Mountain in Great Barrington, Mass., *Ibid.*, p. 551–566.

Collie [1] describes the geology of Conanicut Island, R. I. The oldest rocks are a series of slates of unknown age, into which was intruded a mass of granite, porphyritic in character. This complex was exposed to weathering influences until a bed of débris lay upon its surface. This surface was depressed beneath the sea, and upon it was laid a great series of carboniferous rocks. The complex was, therefore, the Carboniferous shore line. Into the Carboniferous rocks dikes were intruded, and both were folded, metamorphosed, and have in many places become schistose.

Wolff [2] reaches the following conclusions as a result of his detailed study of the Highlands of New Jersey in the vicinity of Hibernia. The rocks are found to consist of distinct bands of gneiss which can be recognized. These layers have once been nearly horizontal, and are folded into an anticlinal dome which has the characteristics of ordinary folds, and has a distinctly recognizable pitch. The rocks of the series have a top and bottom, the latter being at the center of the dome and the top ones at the periphery. One characteristic horizon, a garnet-biotite-graphite-gneiss, must once have existed over a large part of the present area, and the same is probably true of the lower horizons. The foliation, in part at least, is parallel to the bounding planes of the different layers of rocks. The crystallization of the rock occurred during or after the action of the compressing force which folded the rocks and produced pitch but not before, since this structure is inherent in the shape of the minerals as they crystallized. These facts favor the view that the series is a sedimentary one, in which metamorphism and recrystallization took place contemporaneously with the folding and without fusion, and therefore that it is of Algonkian age.

Keith [3] gives the geology of the Catoctin belt. The pre-Cambrian rocks constituting the Blue Ridge core are all of igneous origin. They include quartz-porphyry and andesite, Catoctin schist, and granite. A detailed lithological description is given of each of these rocks and of their alterations. The Catoctin schist and the granite are separated by areas in which the two are intimately intermingled. The Catoctin schist is an altered diabase, and the diabase is believed to be separable into two flows with a time gap between them. An evidence of this is a discordance of structure. The order of the events was probably as follows: (1) Diabase extrusion, (2) granite intrusion, (3) erosion interval, (4) quartz-porphyry and andesite flows, (5) erosion inter-

[1] The Geology of Conanicut Island, R. I., by G. L. COLLIE, Trans. Wis. Acad. Sci., Arts and Letters, Vol. X., 1894–5, pp. 199–230, with Pl. IV.

[2] Geological Structure in the vicinity of Hibernia, N. J., by J. E. WOLFF, Geol. Sur. of N. J., Ann. Rep. for 1893, pp. 359–369, 1895.

[3] The Geology of the Catoctin Belt. by ARTHUR KEITH, Fourteenth Ann. Rep. U. S. G. S. (for 1892–3), Part II., pp. 285–395; and Geol. Atlas of the U. S., Harper's Ferry Folio, U. S. G. S. Washington, 1894.

val (?), (6) diabase flow, and (7) erosion interval. The different lavas have been folded, faulted, and secondary structures have developed within them. Metamorphism was most extensive in the diabase, which has become a well-developed schist. The quartz-porphyry is the least altered.

Merrill[1] describes the disintegration of the granite rocks in the District of Columbia, and finds from chemical analyses, calculated on a water-free basis, that they are very similar to those of the original rocks, and therefore that the rocks are as much disintegrated as decomposed. The chief chemical change is hydration.

Haworth[2] maps and fully describes many areas of pre-Cambrian crystalline rocks of Missouri. These occur in irregular areas and isolated hills extending over an area seventy miles square in the southeastern part of the state. The rocks consist of granites, granophyres, and porphyries, which are occasionally cut by diabase dikes. Some of the granophyres are located between the granite and the porphyry areas, and seem to be a connecting link between them. At other times they are in contact only with the granite or with the porphyry, in which case the connections are traceable in one direction only. It is concluded that all are different facies of a magma belonging to a single period of igneous activity. Associated with the pre-Cambrian are clastic beds occupying small areas, as for example, at the summit of Pilot Knob.

Hill[3] finds in Indian Territory in the heart of the area occupied by the Chickasaw Nation, a granite called the Tishomingo granite, which appears to be of pre-Palæozoic age.

Russell[4] finds as a result of a geological reconnoissance in central Washington that in Okanogan county there are granites, schists, quartzites, and allied rocks. Resting upon the upturned and eroded edges of these crystalline rocks is the Kittitas series, which belongs to the Tertiary system.

Iddings, Weed, and Hague[5] describe and map the geology of the Livington sheet, Montana. Archean crystalline rocks constitute a part of the southern half of the region. These include mica-schists, phyllite, gneiss, and granite. Much of the granite is eruptive and carries angular blocks of other

[1] Disintegration of the Granitic Rocks of the District of Columbia, by GEORGE P. MERRILL, Bull. Geol. Soc. Am., Vol. VI., 1895, pp. 321–332, Pl. XVI.

[2] The Crystalline Rocks of Missouri, by ERASMUS HAWORTH, Missouri Geol. Sur., Vol. VIII., 1895, pp. 84–222 with map and plates.

[3] Notes on a Reconnoissance of the Ouachita Mountain System in Indian Territory, by R. T. HILL, Am. Jour. Sci. (III.) Vol. XLII., 1891, pp. 11–124.

[4] A Geological Reconnoissance in Central Washington, by I. C. RUSSELL, Bull. 108, U. S. G. S., p. 20, with map. Washington, 1893.

[5] Geol. Atlas of the U. S., Livingston, Folio No. 1, by J. P. IDDINGS, WALTER H. WEED, and ARNOLD HAGUE, U. S. Geol. Sur. Washington, 1894.

rocks. The foregoing are cut by veins and dikes of crystalline rocks, both basic and acid. Resting unconformably upon the Archean rocks is the Belt formation, which is supposed to belong to the Algonkian period. This formation is found on the western flank of the Bridger range. The rocks comprise sandstones, conglomerates, slates, and arenaceous limestones. The series is about 2500 feet thick within the area mapped. The Algonkian rocks are overlain conformably by the Cambrian Flathead quartzite.

Eldridge,[1] from a geological reconnoissance in northwest Wyoming, finds that Archean granites, gneisses, and schists of various types form the crest of the Big Horn, Wind River, Absaroka, and Owl-Rattlesnake ranges. In the Wind River and Absaroka ranges the Archean areas are extensive. Resting upon the Archean rocks and in many places deriving material from them, are the rocks of the Cambrian system.

Cross[2] describes and maps the geology of the Pike's Peak sheet. The oldest rocks here found are Algonkian quartzites and allied rocks, which occur as fragments included in the granite. These vary in size from that shown in Wilson park to minor fragments. The Wilson park mass is nearly 4000 feet in thickness, stands on end, and is exposed along the strike for about five miles. Other important masses of quartzite are in Cooper Mountain and Blue Mountain. These masses are cut by minute dikes and are entirely surrounded by granite. Smaller fragments are very numerous. Associated with the quartzites are certain gneisses and schists which almost grade into the quartzites, and probably represent metamorphosed Algonkian strata. Schists also occur, especially in the Cripple Creek district, and these seem to represent earthy metamorphosed Algonkian rocks. Granites and gneissoid granites occupy much the larger part of the Pike's Peak sheet. The more important granites are the coarse-grained Pike's Peak type and a fine-grained granite. The gneissoid granites are but foliated phases of the granites, and between the two there are gradations. All the granites are cut by coarse granitic dikes and veins. The Silurian rocks rest unconformably upon, and derived fragments from, all the previous formations.

Eldridge[3] maps and describes the Crested Butte sheet, Colorado, and finds that on the northwest and southeast corners of the district are Archean areas. These consists mainly of granite and granite-gneiss, with local developments of gneiss and schist.

[1] A Geological Reconnoissance in Northwest Wyoming, by GEORGE H. ELDRIDGE, Bull. 119, U. S. G. S., p. 17, with Geol. Map. Washington, 1894.

[2] Geol. Atlas of the U. S., Pike's Peak Folio, No. 7, by WILLIAM CROSS, U. S. Geol. Sur. Washington, 1894.

[3] Geol. Atlas of the U. S., Anthracite-Crested Butte, Folio No. 9, by GEORGE H. ELDRIDGE, U. S. Geol. Sur. Washington, 1894.

Walcott[1] gives the results of his study of the Algonkian rocks of the Grand Canyon of the Colorado. The following classification of the rocks is adopted :

Cambrian	Tonto	
	Unconformity	
Algonkian	Grand Canyon	Chuar
		Unkar
	Great Unconformity	
Algonkian (?)	Vishnu.	

The Vishnu at the one point examined, due south of Vishnu's Temple, consists of micaceous schists and quartzites, cut by dikes and veins of granite. The Unkar terrane, 6830 feet thick, consists of limestones, sandstones, conglomerates, and intrusive and extrusive basic rocks of various kinds. The basal conglomerate is formed largely of pebbles derived from the upturned edges of the pre-Unkar strata. The Chuar terrane, 5120 feet thick, consists mainly of shales of various kinds, but contains 285 feet of limestone. Resting unconformably upon the Grand Canyon series is the Tonto Cambrian. Before the deposition of the latter the Grand Canyon series was planed to a base level, and all the strata of the series were truncated.

Midway in the lower portion of the shales and limestones of the Chuar terrane the presence of fauna is shown by a minute discinoid or patelloid shell, a small Lingula-like shell (which may be a species of Hyolithes), and a fragment of what appears to be the pleural lobe of a segment of a trilobite belonging to a genus allied to the genus Olenellus, Olenoides or Paradoxides. There is also a Stromatopora-like form that is probably organic.

The entire Grand Canyon series is placed in the Algonkian period or Proterozoic era. Various possible correlations of the Grand Canyon with other series may be made, but it is evident that until characteristic fossils are found in the various terranes now referred to the Algonkian, it will be impossible to make any correlations that will be more than tentative suggestions.

Sapper,[2] in 1894, describes and maps considerable areas of Azoic formations in Guatemala. The lowest formations are gneiss and the higher formations are mica-schists and phyllites, associated with which are crystalline limestones, actinolite-schistt, and quartzites. Closely associated with these schistose rocks are ancient eruptive rocks, including granite, diabase, etc. Whether these Azoic formations are pre-Palæozoic or not cannot as yet be asserted.

[1] Algonkian Rocks of the Grand Canyon of the Colorado, by C. D WALCOTT, JOUR. OF GEOL., Vol III., April–May 1805, pp. 312–330, and 14th Ann Rep. U. S. G. S. (for 1892–3), Part II., pp. 487–524.

[2] Grundzüge der physikalischen Geographie von Guatemala, by CARL SAPPER, J. Perthes' Geog. Anst., Ergänzungsheft, Nr. 113, 1894, pp. 59, with 4 maps.

AUTHORS' ABSTRACTS.

Origin of the Iowa Lead and Zinc Deposits. By A. G. LEONARD. Am. Geol., Vol. XVI., November 1895.

The deposits occur in the northeastern corner of the state and form part of a larger area embracing the southwest portion of Wisconsin and northwest corner of Illinois. The ore occurs in crevices in the Galena and Trenton limestones, and in Iowa most of it has been taken from the upper fifty feet of the Galena beds.

The minerals were originally deposited as sulphides along with the sediments in certain areas where, borne by currents, they first came in contact with abundant organic life. There is no evidence of general diffusion and subsequent concentration by surface decomposition of rocks as apparently the case in Missouri.

At a later period the Galena beds were raised into folds and east and west fissures formed which becoming channels for underground waters were enlarged into cave-like "openings." In the latter the ores mostly occur.

There is nothing to show that the deposits were formed by hot solutions rising through fissures from great depths. On the other hand there is abundant evidence to prove that to the process of lateral secretion is due the deposition of the ores in the crevices and that they have thus been derived from the limestone whence they have been leached by surface waters. There is reason to believe that the Galena limestone contains lead and zinc diffused through it in small quantities. This theory does not necessitate the derivation of the minerals from the rocks immediately adjacent, but they may have been leached for a considerable distance on either side. Thus the metalliferous contents of the country rock would be sufficient to supply the deposits.

The Gold-Silver Veins of Ophir, California. By W. LINDGREN. Fourteenth Ann. Report of the U. S. Geol. Survey, pp. 243–284.

The deposits described are located in the gold belt of the Sierra Nevada near the contact of a *massif* of granodiorite of late Mesozoic

age with older post-Carboniferous, probably also Mesozoic, amphibolite schists. The latter are in places impregnated with slightly auriferous iron pyrites, forming belts or *fahlbands*. The deposits are typical fissure veins forming two systems, one with a west-northwest strike, the other with a northeast strike; all fissures dip southeast or southwest at angles ranging from 20° to 80°. The vein filling is principally quartz, with very little calcite. Native argentiferous gold, with small quantities of auriferous and argentiferous sulphides comprise the ores. The richest ore is usually concentrated in chutes, mostly of elongated form and dipping east on the plane of the vein. In the amphibolite a distinct connection may frequently be noted between the *fahlbands* and the pay chutes on the veins crossing them. Next to the veins the country rock is altered by replacement to a mixture of carbonates, sericite and iron pyrites. This process, to which nearly all deposits of the gold belt are subject, is illustrated by several analyses.

The fissure systems have in all probability been formed simultaneously by a compressive stress acting in a direction parallel to the trend of the Sierra, and the fissuring was attended with considerable horizontal motion. Hot siliceous and carbonated solutions containing heavy metals dissolved in alkaline sulphides ascended the veins, altering the wall rock and depositing the silica and ores in the largely open fissures. Action of percolating surface waters seems out of the question. The auriferous iron pyrites of the *fahlbands* were probably a source of local enriching of the veins, but the derivation of the largest part of the precious metals must as yet be considered an open question. A map of the vein systems accompanies the paper.

Ueber das Norian oder Oberlaurentian von Canada. By FRANK D. ADAMS. *Neues Jahrbuch für Min, etc.*, Beil. Bd. VIII., 1893.

The author having in a former paper shown that the great anorthosite masses supposed by the earlier Canadian geologists to form the upper portion of the Laurentian system, are in reality great igneous intrusions, proceeds in the present article to give an account of a large area of the typical Laurentian to the north of Montreal, in which he deals principally with the petrological character, stratigraphical relation and origin of the Grenville series, which is the true upper portion of the Laurentian. The lower or fundamental gneiss in its uniform character, as well as in its mineralogical and chemical

composition, has the character of an igneous rock. The Grenville series, which appears to rest upon it, frequently has a well-banded character with rapid alternations of various varieties of gneiss, which are in many places interstratified with heavy bands of crystalline limestone, quartzite, etc., has the character of a sedimentary series. A set of analyses of the gneisses, some from the Fundamental gneiss and some from the Grenville series are given, and it is shown that the former have the composition of granite, while the latter have that of sand and clay, a composition quite different from that of any igneous rock, but like that of ordinary sediments. It is also shown that these rocks do not always occur highly inclined, but that over great areas they lie nearly flat or in low undulations, suggestive of thin crust buoyed up by some semi-fluid or plastic material beneath, probably a great batholite granite mass, a portion of which is exposed in one part of the area. The effect of pressure acting after the intrusion of the anorthosites through the Grenville series, is shown in the development of a foliation in the peripheral portion of all the great igneous intrusions, and in the movements which have caused the foliation of the gneiss to follow, and to a certain extent the outline of these more resistant masses. The Grenville series, therefore, comprises certain primeval sediments which have been deeply buried, invaded by great masses of igneous rocks and recrystallized. A map of the area and a photograph of a cliff of the horizontally banded gneiss accompany the paper.

Relations of the Granite and Porphyry Areas in Southeastern Missouri. By CHARLES R. KEYES. Geol. Soc. of Am., Philadelphia, 1895.

As is well known the granitic rocks of Missouri are the only massive crystallines occurring in the Mississippi basin between central Arkansas and Lake Superior and between the Appalachians and the Rocky Mountains. They are, moreover, the most ancient rocks exposed within the limits of the region. As irregular, discontinuous fields they are scattered over a district of about 3000 square miles.

Lithologically the crystalline rocks comprise both acid and basic varieties. The latter, however, are unimportant and occur usually as narrow dikes; the former comprise two well-marked structural phases, one a coarse-grained granite and the other a porphyry. Mineralogic-

ally and chemically the two kinds are practically identical. It is quite manifest that the two phases gradually merge into each other, and the porphyry is to be regarded as the surface facies of the coarse-grained rock.

Heretofore no explanation has been advanced regarding the peculiarities in the geographic distribution of the granitic and porphyritic masses. It is the purpose of the present note to ascribe the surface distribution, as now existing, to certain stages in the physiographic development of the region. In its main features the crystalline district of Missouri is a semi-alpine country. The prominent solitary peaks are irregularly distributed, and form what has been called the St. Francois Mountains. This group of hills constitutes the eastern end of the crest of the Ozark uplift. The extremes of altitude are about 500 and 1800 feet above tide level.

Most prominent among the physiographic features presented are two plains standing at different levels. The first is a deeply incised constructional surface — the Tertiary peneplain; and the second is a moderately dissected plain lying at a lower level — the Farmington lowland. The great Tertiary peneplain forms the general surface of the Ozark uplift. In no part of this raised region, unless it be in the St. Francois district, does any portion of the pre-Tertiary surface project above the broad constructional plain, and even here the nearly uniform height to which the numberless peaks rise would indicate that they also were practically obliterated in Tertiary times, at least as prominent surface features. The Farmington lowland is formed by a broad belt of rather even surface which cuts across the eastern end of the crest. Its general elevation is about 1000 feet above mean tide, a level which is 700 to 800 feet below the horizon of the great peneplain. The lowland is manifestly a plain of denudation. It is the product of a former cycle whose work was interrupted before completion. In point of time this cycle was a later one than that represented by the Tertiary peneplain, and immediately preceded the present one.

In the areal distribution the principal granite field is confined to the northeastern part of the crystalline district and occupies about one-fifth of the entire area. The particular fact to be noted regarding it is that it lies entirely within the lowland plain of denudation. The inference is clear that at this point in the Ozark uplift the porphyritic surface facies of the granite has been removed through erosion in part perhaps in pre-Cambrian times but largely during a more recent period.

The fact that the general surface facies of the acid rock has been actually eroded is shown by several high isolated hills which rise out of the granite area. Some of these, as Knob Lick for instance, are still capped by porphyry. They show further that the granite, to a depth of over 400 feet has been removed in addition to the surface shell of porphyry.

To recapitulate:

1. The granites and porphyries are very closely related genetically, and are to be considered as facies of the same acid magma.

2. Whatever may have been their origin, whether from a few or many points of extravasation, the present relations of the two are that the porphyry is an upper and surface facies of the granite, the thickness of the former being variable, having been originally unequally developed in different places and subsequently modified both ancient and recent erosion.

3. The present geographic distribution of the granites and porphyries is the outcome of very recent changes in the topographic configuration and not of very ancient origin as it has been usually regarded.

4. The existing areal relations of the principal masses of the acid rocks may be traced directly to the systematic and wide-spread physiographic effects arising from recent orogenic action.

5. An element of uncertainty regarding the geological age of the massive crystalline rocks now prevails and an exact determination may always remain a problem yet to be solved.

6. The basal complex of Archæan schists exists in the state within a very moderate distance beneath the highest Palæozoics. It differs widely in lithological characters from the crystallines usually referred to that age, but closely approaches the more typical Archæan rocks of other districts.

Syenite-Gneiss (Leopard Rock) from the Apatite Region of Ottawa County, Canada. By C. H. GORDON. Bull. Geol. Soc. Am., Vol. VII., pp. 95–134. Rochester, December 1895.[1]

In the collections of the Canadian Geological Survey at the World's Fair there were displayed specimens of a rock showing a peculiar

[1] Thesis presented for degree of Doctor of Philosophy, University of Chicago, June 1895.

lumpy aggregation of the feldspathic constituents. During the summer of 1894 the author visited the region from which this rock was obtained and studied its relations in the field, subsequently studying in the laboratory the material obtained.

The rock was found to occur at High Rock, an apatite mine on the west bank of the Du Lievre River about twenty miles above Buckingham, in a series of dikes intersecting quartzites, and pyroxenites. In general the rock has the composition of a syenite though in places carrying more or less quartz, and is often associated with the apatite deposits, but no attempt is here made to show their genetic relationship.

The dike rock in its various phases shows more or less evidence of dynamic action, and the term syenite-gneiss is applied to it. It presents three distinct phases which the author designates as *coarse-grained syenite-gneiss, ellipsoidal syenite-gneiss and streaked syenite-gneiss.* The first consists of a coarse-grained mixture of microcline and monoclinic pyroxene with a small but variable amount of quartz. The rock is divided into irregular blocks by obscure seams which apparently represent recemented cracks. In the second phase it consists of irregularly ellipsoidal or ovoid masses of feldspar and some quartz separated by narrow anastomosing partitions of green interstitial material, chiefly augite. Frequently the crystals of pyroxene, which are elongated in the direction of the prism, lie transverse to the interstitial layer and thus present a more or less pronounced radiate appearance. From the rounded ellipsoidal forms the feldspathic lumps vary to more and more flattened forms until the structure merges into the third phase, in which the pyroxene layers are arranged in parallel bands alternating with somewhat thicker feldspathic layers. Here there is marked diminution in the size of the grains, while quartz becomes relatively more abundant. Large crystals of apatite appear in places inclosed in the ellipsoidal rock, and having the ellipsoids arranged concentrically about them. Masses of apatite also occur in the streaked rock, crushed to a more or less granular, saccharoidal condition, and around them the streaks of pyroxene curve concentrically.

Under the microscope the coarse-grained rock is found to be composed chiefly of microcline, with a much smaller proportion of augite and a variable but usually small amount of quartz. The rock is intersected in various directions by fine, granular bands, made up of microcline and plagioclase, the latter usually containing small nodular

quartz inclusions. The grains of augite sometimes show the effects of mechanical movements in the fracturing of grains which lie in contact with the granular bands.

In the ellipsoidal rock the granular bands are more pronounced and strongly marked by the presence of pyroxene. Quartz appears in greater amount than in the coarsed-grained rock. In the streaked gneiss all the constituents are finer grained. Hornblende appears here frequently, sometimes in sharply idiomorphic crystals. Both in their field relation and in their microscopical structure these rocks show a gradation from the coarsely crystallized rock to the fine-grained streaked gneiss.

In the classification of gneisses it is suggested that the term gneiss be used in the broader structural sense following the prevailing usage among Canadian geologists; where the origin of the rock is known a corresponding qualifying term may be used as diorite-gneiss. Where the origin is unknown, the ending "ic" may be given to the qualifying term to show its structural relations, as dioritic-gneiss. In harmony with this view the rock under consideration would be a pyroxene-syenite-gneiss. As to the origin of the ellipsoidal structure the evidence, while in many respects incomplete, involving as it does much that is as yet little understood in the metamorphism of rocks, seems on the whole to favor the hypothesis of dynamic metamorphism.

Briefly summarized this supposes:

1. That the structure characterizing the Leopard rock is due to orographic agencies and represents an intermediate stage in the development of a streaked augite-syenite-gneiss out of an augite-syenite, which was distinguished by a coarsely crystallized structure and by a somewhat irregular aggregation of pyroxene.

2. That the distribution of the pyroxene has been effected by the solution of portions of the original constituents and their recrystallization along lines marking the location of the cracks.

3. That with continued pressure these lumps have been more and more drawn out, the process being accompanied by recrystallization until the rock assumed the streaked gneissoid form.

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